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Evaluation of Trenchless Sewer Construction at South Bethany Beach, Delaware

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EVALUATION OF TRENCHLESS SEWER CONSTRUCTION AT SOUTH BETHANY BEACH DELAWARE



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CONSTRUCTION AT SOUTH BETHANY BEACH, DELAWARE

BY

Lee J. Beetschen
William C. Henry
Edward H. Richardson Associates, Inc.
P. O. Box 675
Newark, Delaware 19711

Grant No. S-800690

Project Officer

Hugh Masters
Storm and Combined Sewer Section (Edison, N.J.)
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

This study was conducted in cooperation with
Sussex County Council
Georgetown, Delaware 19947

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

The work described herein was undertaken to evaluate trenchless sewer construction. Based on an evaluation of the results of the study, using polyvinyl chloride pipe, this method proved to be less costly, safer and more rapid than conventional sewer construction.

Francis T. Mayo
Director
Municipal Environmental Research
Laboratory

PREFACE

The 1976 Needs Survey projected that over 90,000 miles of new sewage collection pipe, at a cost of approximately \$17,000,000,000, would be required nationally by 1990. In developing these costs, it was assumed that conventional construction methods would be used to place the sewer pipe. Obviously, even a minor improvement in these methods could result in a significant savings in the overall Construction Grants program and, thus, ultimately to the individual tax payer.

The research undertaken for this project was directed at evaluating a new construction method which showed promise of providing such cost benefits as well as being a safer and more environmentally sound means of installing sewer pipe. At South Bethany Beach, Delaware, a trenchless method of sewer construction was compared against conventional methods under similar site conditions. The cost data developed during the course of the project indicated significant savings through the use of the trenchless method. In the most conservative form of cost comparison, the trenchless method was 16 percent less expensive than the conventional.

ABSTRACT

The purpose of this project was to determine whether the trenchless method of sewer construction had inherent cost, safety and other advantages over conventional methods of sewer construction. Under similar site conditions, the trenchless method was more cost effective than conventional means based on the actual unit bid price (50%), on complete sewer installation including manholes, wyes and laterals (16%) and on labor savings (23%). Eight inch polyvinyl chloride pipe with rubber gasketed joints was used in the conventional area, whereas eight inch polyvinyl chloride solvent welded pipe was used for the trenchless method.

The trenchless method does not appear to be suited for urban areas where significant subsurface utilities exist, nor where rock or boulders exist in high density. However, the system is uniquely adapted to high water table areas, and its flexibility of application under varying soil conditions is wide ranging. The potential for infiltration is significantly less and, with proper field control, the trenchless method results in less deflection and horizontal and vertical misalignment. With open trenching reduced to a minimum, the method is safer than the conventional technique, particularly where deeper cuts are required. From an environmental standpoint, the trenchless method provides less disruption to traffic, and represents an improvement in sediment runoff control and noise reduction.

This report was submitted, in fulfillment of EPA Grant No. S-800690, by the Sussex County Council under the sponsorship of the Environmental Protection Agency. Work was completed as of December 12, 1977.

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Special acknowledgement is made to Mr. Hugh Masters, EPA Project Director for his patience, guidance and overall assistance on this project.

SECTION 1

INTRODUCTION

GENERAL

Continuing increases in material and labor costs associated with gravity sewer construction have created an interest in the development of new construction techniques to temper the impact of the rising costs on the ultimate user. Except for equipment improvements, contractors have been using basically the same methods for gravity sewer construction for decades. The open trenching method with stone bedding, dewatering and sheeting, as required, has been the standard. The costs associated with these latter three items can be significant where unsuitable site conditions are encountered. Furthermore, the potential for injury or death increases dramatically when deeper excavations are required.

Equipment to install gravity sewers without open trenching was developed in England in the late 1960's. Continued improvements by the manufacturer, Badger Systems Plough, Ltd. led to the evolution of the Badger Minor method which consisted of plowing in solvent welded polyvinyl chloride (PVC) pipe on a grade established using a laser controlled unit. Other equipment manufacturers have developed similar systems capable of placing pipe by the plow-in method. The term "trenchless method" is generally applied to all such methods.

OBJECTIVE

The general objective of this project was to compare conventional and trenchless methods under similar site conditions during an actual gravity sewer construction project. Emphasis was placed on development of cost information and the quantification and tabulation of methods used and the rates associated with each construction technique. A complete post construction survey was conducted in order to determine the quality of the constructed sewers in terms of horizontal and vertical alignment, infiltration and internal pipe conditions.

SECTION 2

CONCLUSIONS

1. The trenchless sewer method was determined to be more cost effective than conventional means as indicated by cost information developed using three (3) methods:
 - a. On the basis of actual bid price, the installed costs for 8" (20.3 cm) polyvinyl chloride (PVC) gravity sewer mains for conventional and trenchless areas were \$15 and \$9 per lineal foot (\$49.21/m and \$29.33/m), respectively.
 - b. On the basis of computed costs for complete PVC sewer installation including wyes, manholes and laterals, the costs per lineal foot for conventional and trenchless systems were \$23.15 and \$19.39 (\$75.90/m and \$63.57/m) respectively.
 - c. On the basis of computed costs for labor only, the differential was \$.84/lineal foot (\$2.76/m) in favor of the trenchless method.
2. Comparisons between both techniques with regard to compliance with invert elevations at the manhole were developed in two ways:
 - a. In the conventional area, 31% of the "as-built" invert elevations were within the specified tolerance of .04 feet (1.22 cm). In the trenchless area, 40% of the invert elevations were within this specified tolerance.
 - b. In many cases the trenchless pipe was not pulled to the manhole. The resulting gap, in the main, which in some cases was as much as 40 feet (12.2 m), was completed with pipe installed using conventional methods. By computing the projected invert elevation at the same grade, 75% of these computed invert elevations were within the vertical tolerance.
3. In most cases, trenchless pipe was rife-barrel straight prior to the installation of laterals. Due to the construction crew's unfamiliarity with mains installed with this system, the completed main, i.e. after lateral installation, had poor alignment in both the horizontal and vertical planes. Using a laser beam, and taking measurements in 50 feet (15.24 m) increments between manholes, the following data were derived:
 - a. Ninety three percent of measurements taken in a test section in the conventional area were within the vertical tolerance of .04 feet (1.22 cm). Sixty percent of the measurements were within the specified horizontal requirement of 0.17 feet (5.2 cm).

- b. In the trenchless area 78% of the measurements were within the vertical tolerance, whereas only 50% of the horizontal measurements were acceptable.
- 4. Infiltration Tests - Sewer systems in both areas utilized rubber gasketed precast manholes and water tight manhole inserts. They differed in that solvent welded joints were used in the trenchless area and conventional bell and spigot joints with rubber gaskets were installed in the conventional area. The trenchless mains were completely dry. In the conventional area, measured flows ranged between 16 and 44 gallons per inch of pipe diameter per mile of pipe as taken over a 24-hour period.
- 5. Closed Circuit Internal Television Inspection - On the basis of internal inspection, the trenchless and conventional systems were found to be in excellent condition. Only one off-set joint was found in the trenchless area, none in the conventional.
- 6. The presence of subsurface storm conduits, electrical television and telephone conduits did not significantly hamper construction activity in the trenchless area.
- 7. Based on observations made during construction, the trenchless method has several significant advantages over the use of conventional methods:
 - a. In high water table areas, the need for dewatering is significantly less.
 - b. If adequately planned, the trenchless method results in less disruption to traffic.
 - c. Potential for infiltration is significantly less.
 - d. With proper field control, the trenchless method results in less deflection and horizontal and vertical misalignment.
 - e. The system can be used for installing numerous subsurface utilities including gas, water, electric, telephone and cable television service. If permitted by local building codes, several of these utilities could be installed simultaneously as a cluster.
 - f. The trenchless method represents an improvement in certain environmental areas, particularly in sediment runoff and noise reduction.
 - g. The trenchless method is adaptable to almost all subsurface soil conditions. The flexibility of application is wide ranging.

- h. The trenchless method is safer than conventional, particularly where deep trenching is required.
- 8. The trenchless method has certain disadvantages as compared to the conventional method most of which can be minimized by proper design and construction techniques:
 - a. The method is not suited to the following areas:
 - 1. Urban areas where significant subsurface utilities exist.
 - 2. Where rock or boulders exist in high density.
 - 3. Roadways with rigid paving unless preceded by saw cutting and removal of sufficient paving to allow placement of the plow and expander.
 - b. Extreme care is required on the part of the engineer in the development of topographical information. The extent of topographical data required may be greater than for conventional. The construction rights-of-way must incorporate those properties where the welded pipe will be positioned prior to pull.
 - c. Care must be taken in defining the location of subsurface utilities on the construction drawings.
 - d. Sewer pipe could not be placed to depths greater than 7 feet (2.1 m) using the equipment evaluated for this project unless the upper portion was trenched to a width great enough to accommodate the Badger. However, other systems are available which can plow to greater depths without open trenching.

SECTION 3

RECOMMENDATIONS

This investigation has demonstrated that the trenchless method of sewer construction is practical and cost effective when compared to conventional means. In addition, the method has inherent environmental and safety benefits superior to conventional construction. The need for further research on the method is not required. It is recommended that those contractors electing to use the trenchless method for sewer construction be accepted on an equal basis by the U. S. Environmental Protection Agency in the Construction Grants Program.

SECTION 4

DESCRIPTION OF SITE

GENERAL

The location of the project was in the Mid-Atlantic region of the United States, specifically, the coastal area of Sussex County which is the southernmost of the three counties which comprise the State of Delaware, see Figure 1. The construction was part of a contract to provide wastewater collection and transmission facilities for the South Bethany Sanitary Sewer District.

The South Bethany District, see Figure 2, includes the Town of South Bethany and the developments of Bay View, Middlesex Beach and Sea Colony. These are resort oriented communities with less than ten percent permanent population. Being a resort area, dwellings and businesses are active from Memorial Day through Labor Day.

Except for the winter of 1976, the winters in this area are generally mild. The period during which there is frost on the ground is usually limited to January and February and parts of December and March. Despite the unusually cold winter during the project period, only nine instances of daily workday temperatures less than 40° F (4.4° C) were recorded in the field during the active innovative construction period. The depth of frost on the ground is normally less than twelve inches (30.5 cm).

The topography of the project area is generally flat ranging between 2.5 feet (.76 m) to 11.0 feet (3.35 m) above mean sea level. The ground elevation where the pipelines were installed was mostly between 3.0 feet (.91 m) and 5.0 feet (1.52 m) above mean sea level. Most of the project area is described as "Fill Land" in the "Soil Survey of Sussex County, Delaware" prepared by the United States Department of Agriculture Soil Conservation Service and issued in May 1974. Based on field logs maintained during construction, the substrata one foot below grade consisted of fractional lenses of sand and organic material. This area previously was marshland through which canals were dredged. The excess dredge material was used to raise the elevation of the land between and adjacent to the canals to create additional resort land, suitable for development, with boating access to each lot.

Each peninsula created between the dredged canals is generally 230 feet (70.1 m) to 250 feet (76.2 m) in width and the water table closely follows the tidal changes because of the generally sandy nature of the soils within the range of the groundwater table. The groundwater level was most commonly between 2.5 feet (.76 m) and 5.0 feet (1.52 m) below ground level in most of the project area but was found to be deeper in some areas where the ground elevation approached 11.0 feet (.91 m) above mean sea level.

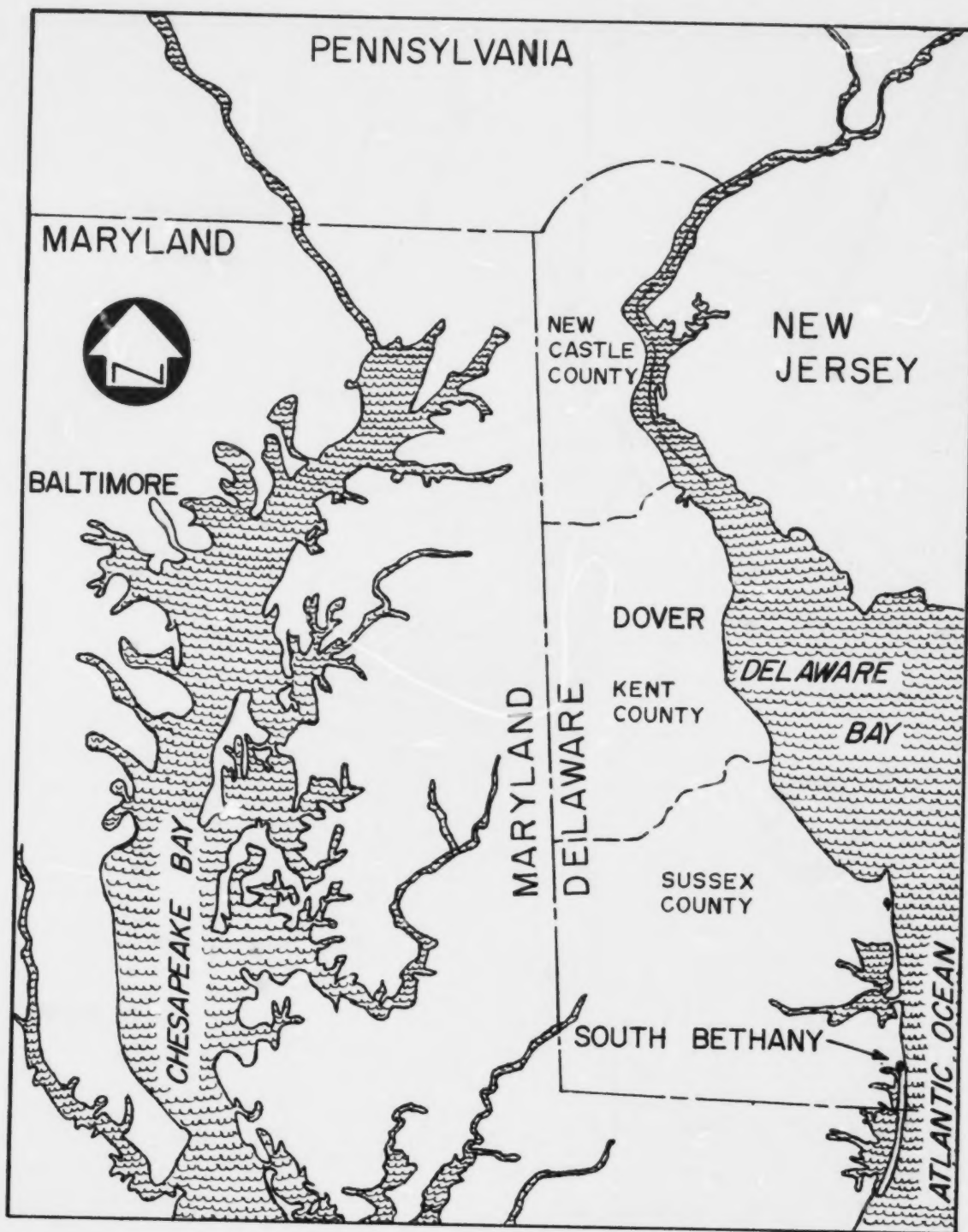


Figure 1. General Location Map

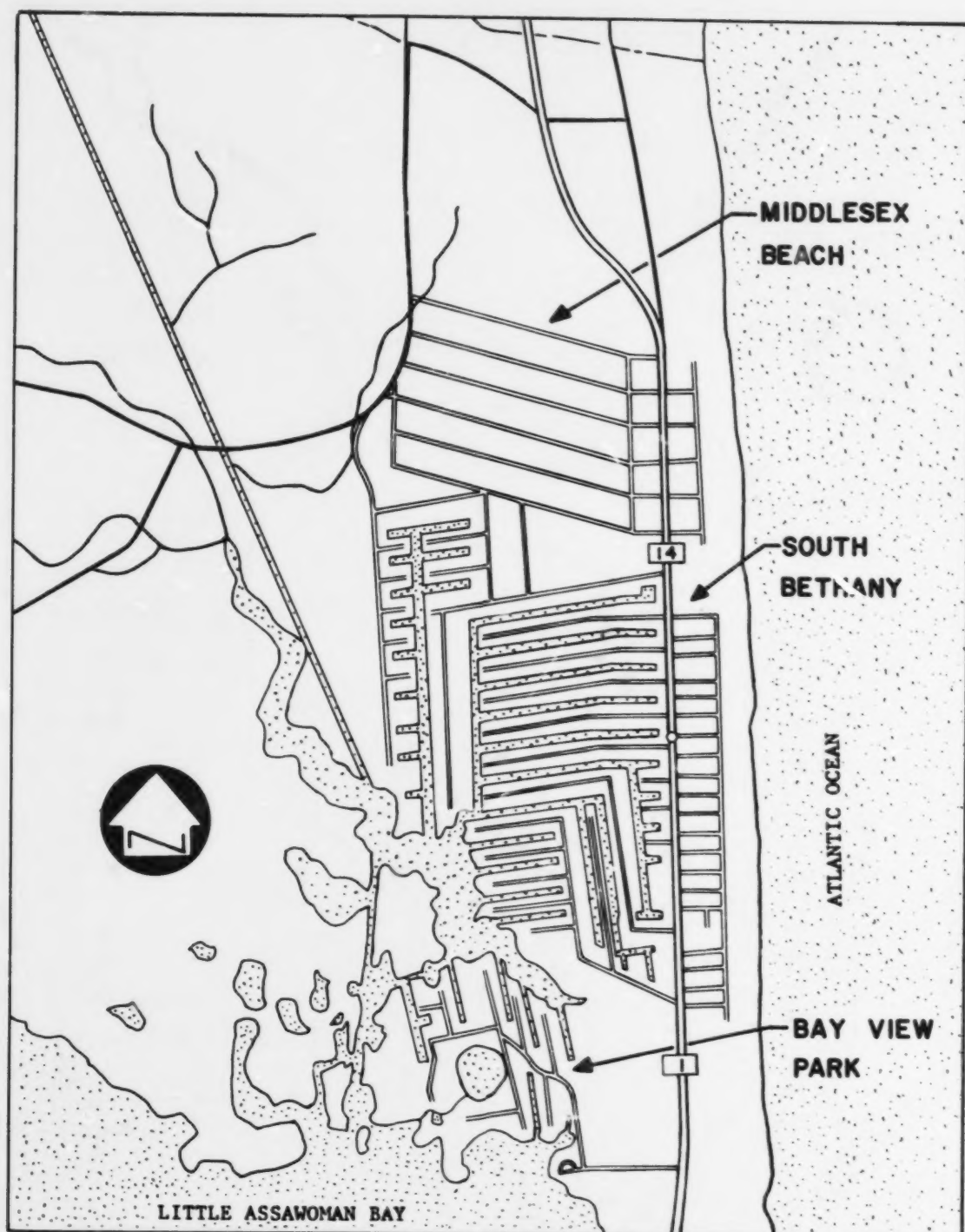


Figure 2. Project Location

This water table data is based on measurements taken throughout the project period.

The quality of the surface waters of the canals in the project area had deteriorated with development to the point where the shellfish activity was discontinued by State order. Until 1968, there were no regulations covering on-site wastewater disposal systems and most buildings were equipped with septic tanks many of which were undersized. In addition, many of these had inadequate leaching facilities which permitted septic tank effluent to move rapidly to the canals.

Groundwater quality sampling was conducted before, during and after construction in an attempt to determine the impact on quality of both conventional and trenchless sewer installation methods. The results of this study are given in Section 7.

Most of the roads within the project area were constructed of two to three layers of tar and chips, while a few were loose stone and dirt. There were no central water or gas pipelines to be avoided but there were a few storm water culverts and electric services. The most commonly encountered underground utility was telephone service, especially small lines crossing roads to serve houses. The project area presented generally less underground interferences from existing utilities than the average, significantly developed residential community.

SPECIFIC PROJECT INFORMATION

The project involved the construction of a total sanitary sewage collection system for the South Bethany Sanitary District. Both conventional and trenchless techniques were utilized to allow a comparative analysis of these methods under similar site conditions.

Referring to Figure 3, the trenchless method was used in the South Bethany and Bay View Park areas on the bay side of U.S. Route 1. Conventional methods were used on the ocean side of U.S. Route 1 in South Bethany and in the landward side of Middlesex Beach.

The overall project involved the construction of approximately 90,000 lineal feet (27,432 m) of gravity collectors, nine lift stations and three pump stations. The gravity sewers were installed either in the center of the road or on the shoulder. A tabulation of sewer lengths installed for each pipe diameter and pipe material is shown in Table 1. A portion, approximately 5,000 feet (1,524 m), of the polyvinyl chloride pipe and all of the reinforced concrete and asbestos cement pipe in the innovative area were installed conventionally.

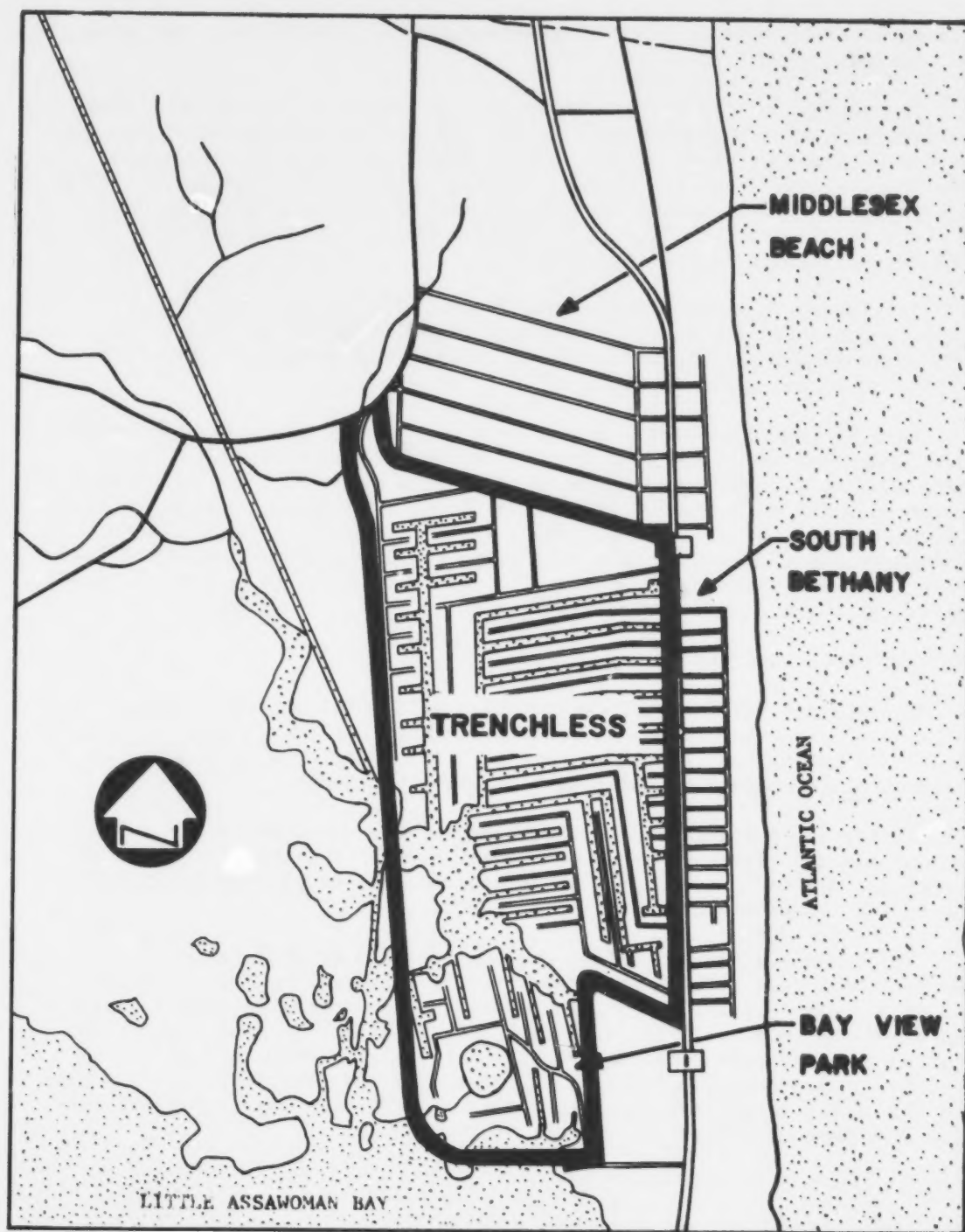


Figure 3. Trenchless and Conventional Construction Areas

Table 1

Length of Sewer Installed

CONVENTIONAL

<u>Pipe Diameter</u>	<u>Pipe Material</u>	<u>Pipe Length (Feet)</u>	<u>Pipe Length (Meters)</u>
8 Inch (20.3 cm)	Polyvinyl Chloride Bell & Spigot	37,367	11,389
10 Inch (25.4 cm)	Polyvinyl Chloride Bell & Spigot	659	201
12 Inch (30.5 cm)	Polyvinyl Chloride Bell & Spigot	3,641	1,110
15 Inch (38.1 cm)	Polyvinyl Chloride Bell & Spigot	7,648	2,331
Total		49,315	15,031

INNOVATIVE AREA

<u>Pipe Diameter</u>	<u>Pipe Material</u>	<u>Pipe Length (Feet)</u>	<u>Pipe Length (Meters)</u>
8 Inch (20.3 cm)	Polyvinyl Chloride Solvent Weld	31,720	9,668
8 Inch (20.3 cm)	Reinforced Concrete Bell & Spigot	6,220	1,896
8 Inch (20.3 cm)	Asbestos Cement Pipe	2,509	765
Total		40,449	12,329

The presence of manmade lagoons and natural water ways imposed a significant limitation on the design of the gravity collection system, particularly in the trenchless area. Changes in direction of flow are normally limited by designers of collection systems, but at this location

could not be avoided, thereby resulting in a significant number of short mains. More than 96 percent of the trenchless pulls were less than or equal to 400 lineal feet (122 m).

The trenchless equipment used on this particular project had a depth limitation of 7 feet (2.13 m) below grade. The average depth of installation in the trenchless area was 4.0 feet (1.22 m) below grade and the maximum installation depth was 6.5 feet (1.98 m).

SECTION 5

THE BADGER SYSTEM

HISTORY OF THE BADGER

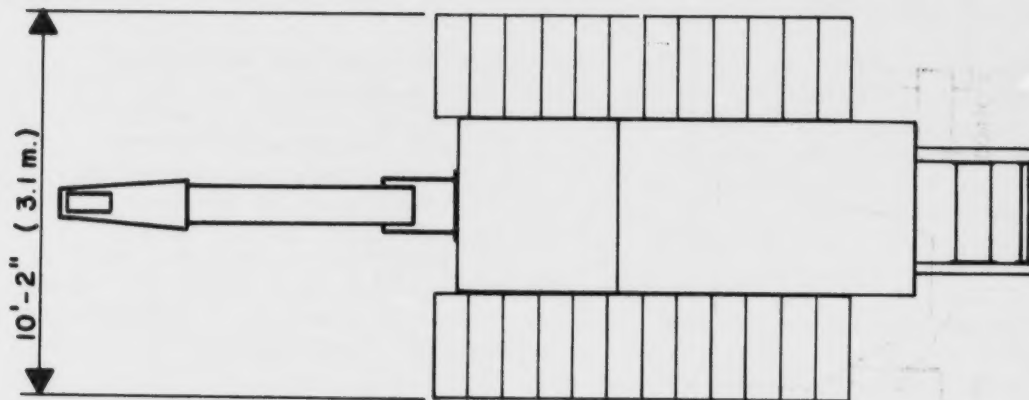
The innovative part of this construction contract was approached with the position that the project should take advantage of any innovative construction equipment having the potential of installing sanitary sewers with sufficient accuracy at less cost and environmental disturbance than with conventional means. Although other types and brands of equipment were pointed out in the Special Provisions of the contract specifications, the lowest responsible bidder proposed the use of the Badger Minor. Discussion in this report is, therefore, limited to the Badger machinery since comparable information on the other types and brands of equipment was not developed. However, based on a review of information gathered during the initial phase of the project, there appears to be other equipment capable of giving similar performance.

The first Badger Minor was built by the Badger Systems Plough Ltd. of York, England and placed in operation in 1965. The Badger Minor Plow machine was built on a British manufactured International Model LTD20 crawler tractor fitted with a 135 H.P. Rolls Royce diesel engine. Referring to Figure 4, the tractor is about 18 feet (5.49 m) long and the overall length of the unit with the plow attachment is 30 feet (9.14 m). The working weight of the total Badger Minor plow machine is about 25 tons (22.7 metric tons). The tracks are 32 inches (81.3 cm) wide resulting in a ground pressure of 12.2 psi (.857 Kg/cm²). The overall width of the complete unit is 10'2" (3.10 m) and overall height is 10'6" (3.20 m).

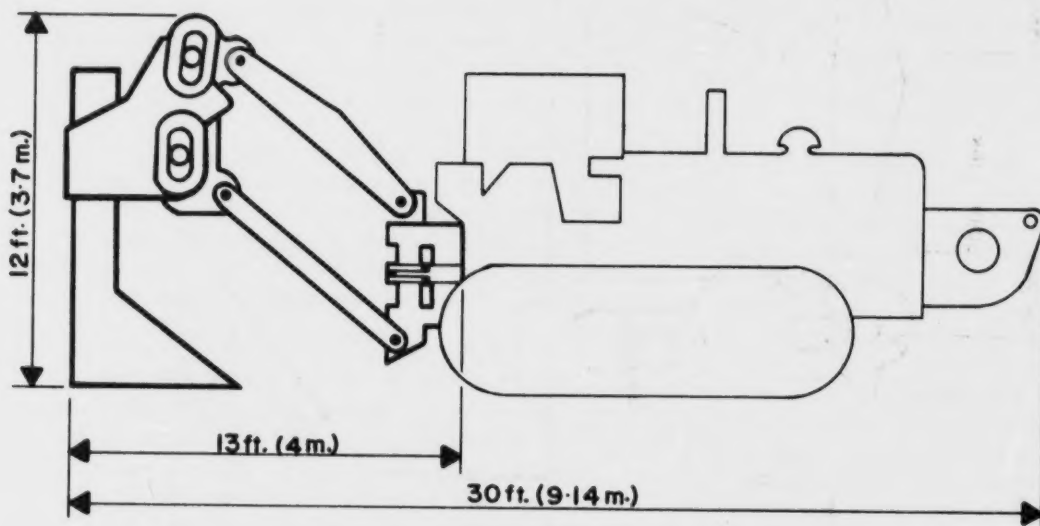
The component parts of the Badger Plow linkage are identified in Figure 5. According to the manufacturer, the principles and design of the linkage insure that the forces on the tractor result in the ground pressure beneath the tracks remaining nearly uniform in operation under a wide range of conditions. This reduces any tendency for the plow tractor to nose down or up, thereby enabling the tracks to develop maximum pull while minimizing surface disturbances.

The Badger Minor was used for installation of agricultural drainage and irrigation piping 6 inches (15.2 cm) or less in diameter generally installed from 3 to 4 feet (.91 - 1.22 m) below grade. This work was done first by the "pull in" method and later by the "feed down" method using flexible pipe. The "feed down" equipment was also made to accommodate single and multiple simultaneous installations of electric cables, telephone ducts, gas and other utility conduits. See Figure 6 for illustration of the two aforementioned installation methods.

The "feed down" method utilizes the Badger blade with a chute attached to the rear. Flexible-plastic pipes or cables are then fed down through the chute as the plow machine moves forward. Small dia-



PLAN



ELEVATION

Figure 4. Badger Minor Dimensions

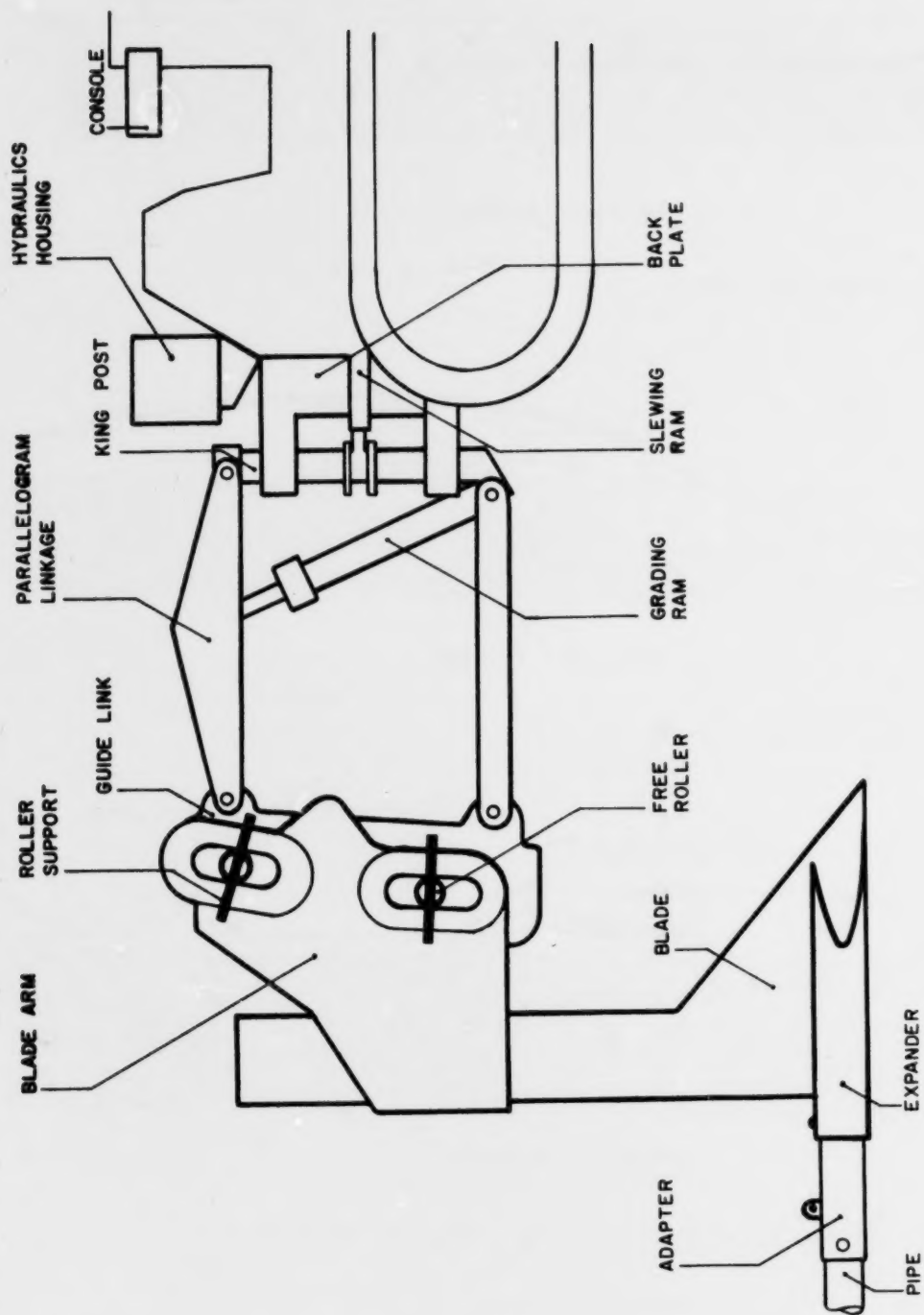
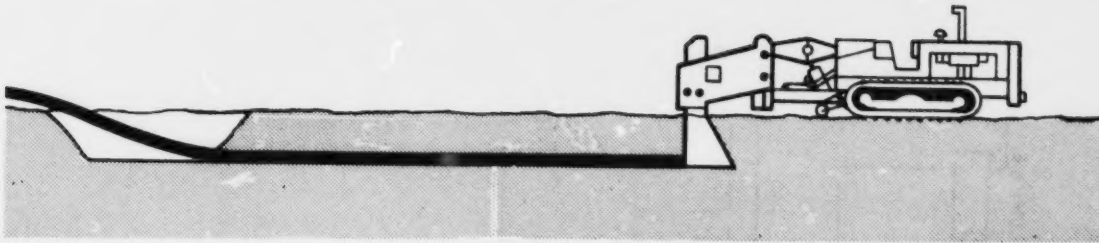


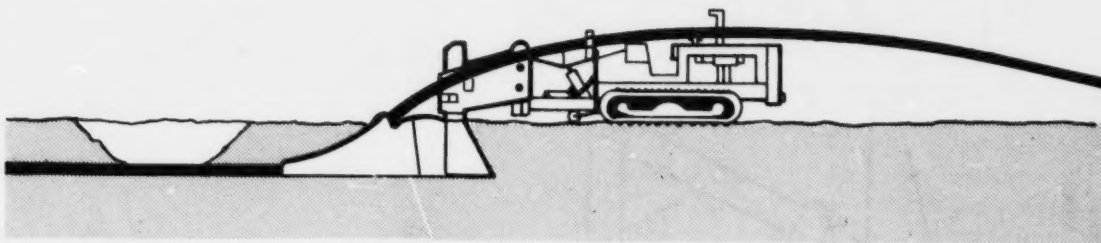
Figure 5. The Badger Linkage

PULL IN METHOD



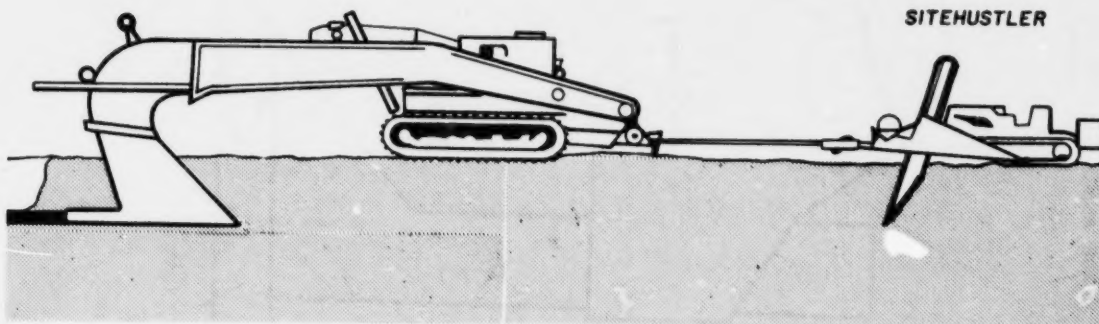
BADGER MINOR

FEED DOWN METHOD



BADGER MINOR

PULL IN METHOD



BADGER MAJOR

Figure 6. Trenchless Sewer Installation Methods

meter flexible pipe and cable are usually uncoiled from a reel mounted on the Badger tractor. Drainage pipe with less flexibility is pre-assembled in long lengths ahead of and parallel to the Badger and fed down through the chute. To improve drainage characteristics, gravel may be installed simultaneously through a hopper attached behind the pipe chute.

In order to pull in larger pipes at a deeper depth, the first Badger Major was built and placed in operation in 1966. Although it is built on the same BTD 20 tractor, as can be seen from Figure 6, the Major is a much larger machine overall and designed to obtain all of its draw bar pull and steering through cables attached to the Sitehustler which serves as an mobile winch machine. The Badger Major has a depth capability of 10 feet (3.05 m) as opposed to approximately 7 feet (2.13 m) for the original Badger Minor. Several who were involved in this project witnessed, in England, a 328 foot (100 m) length of 22 inch (56 cm) diameter PVC interceptor sewer pipe installed at a depth of 9 feet (2.74 m) below grade with a Badger Major.

Because of the high cost of the Badger Major Equipment, about \$350,000 (£ 150,000) in 1974, the Badger Minor linkage has been increased in depth capability and strength and used with a winch equipped tractor to install pipes up to 12 inch (30.5 cm) diameter and to depths of 7.5 feet (2.29 m). This new machine is called the Badger Mark II which is available today to readily attach to Caterpillar, International, Allis-Chalmers and other brands of crawler tractors of suitable weight and power in their standard manufactured form.

When the soil conditions, depth of installation, length of pull and/or pipe diameter require drawbar pull approaching the limit of the plow tractor, the manufacturer advises that pulling assistance should be added from another tractor. This assistance may be derived by a towing tractor or a stationery unit with a suitable winch and cable attached to the plow tractor.

The manufacturer of the Badger equipment has suggested a number of techniques to make longer pulls and achieve greater depths without disturbing the accuracy of the installation. One technique utilized in this project was pre-ripping the ground close to or at the desired installation elevation without the pipe attached. This method reduced the amount of drawbar pull required during pipe installation and also provided a means of checking for unknown buried obstacles such as large logs or rocks.

Where sticky subsoil is encountered, pumping water down through the plow blade to the expander serves to lubricate the pipe and ease its installation. In addition, where space and surface conditions permit, the ground level can be lowered with bulldozers or pans to install pipes deeper than 7.5 feet (2.29 m).

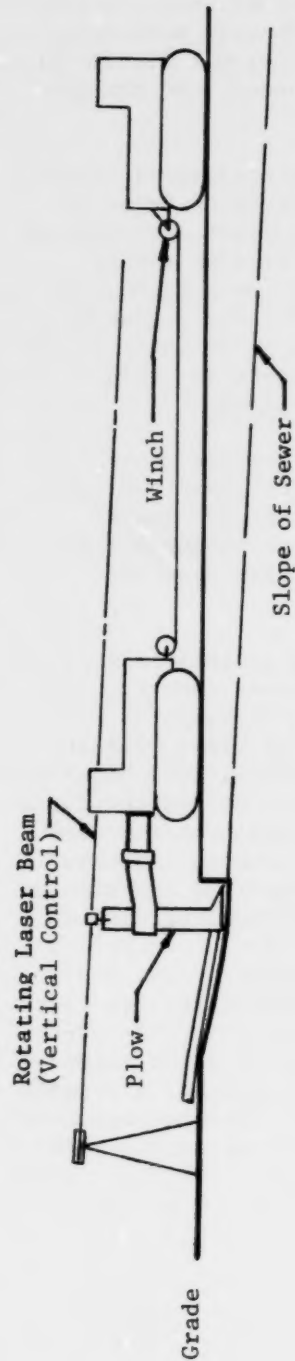
The maintenance of horizontal and vertical alignment has also undergone several evolutionary steps. Grade control was first accomplished by a technician sighting a target on the plow through a level set at the design slope of the pipe utilizing a radio linkage connected to operate the hydraulic grading valve on the plow machine. This method of control was later changed to an electrical cable link and the technician, sighting a target on the plow through a level, controlled the elevation of the pipe being installed by a hand held box with switches which could move the hydraulic cylinders on the plow machine.

The currently recommended and most refined grade and steering control is accomplished with a laser beam rotating in a plane set at the design slope of the pipe which is being installed. Another laser beam oscillates in a vertical plane parallel to the alignment of the pipe. The arrangement of the Badger machinery and laser equipment is illustrated in Figure 7.

The Badger Minor was first used in Delaware for sanitary sewer installation for placing 8 inch (20.3 cm) diameter polyethylene pipe in a private development in the Town of Bethany Beach, very close to and slightly north of the project site. This effort involved about eight pulls and amounted to approximately 1200 feet (365 m) of pipe installed. Vertical control was achieved by a technician who, sighting a target on the plow through a level set at the design slope of the pipe operated the machine's solenoid control valves via an electrical cable. Numerous unexpected underground obstacles were encountered, the positions of which had not been accurately documented. These obstacles, consisting of water pipes and electric cables, were either removed or grades were adjusted to accommodate them.

The next project involved the installation of more than 5000 feet (1525 m) of 8 inch (20.3 mm) diameter sanitary sewer in a private mobile home park. The utilities installed were solvent weld joint PVC sewers and smaller diameter water lines. This installation used the same grade control system for the sewers as in the aforementioned project. Some pulls were made in a cleared path through a wooded area and preripping was done to clear any heavy roots which might disturb the uniformity of invert elevation.

Before the contract for 60,000 feet (18,288 m) for Bethany was advertised, it was decided to let a contract for a small segment of the work to familiarize potential bidders with the Badger system. This pilot contract involved about seven pulls of various lengths of 8 inch (20.3 cm) diameter PVC pipe between 200 and 300 feet (61 - 91 m) in length with solvent weld joints. This contract was the first local project with the Badger Minor utilizing a laser beam for vertical control. The laser detector was used to trigger indicator lights which signalled the Badger operator to actuate the plow's hydraulic vertical control manually.



Elevation

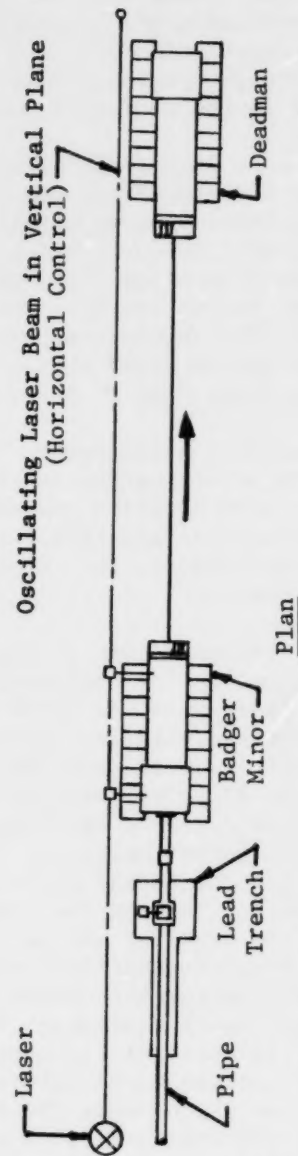


Figure 7. Trenchless System Layout

Since the bids received for the Bethany sewer project contained prices for innovative construction that were higher than conventional prices, the innovative work was transferred to the South Bethany sewer project. Advertisements for bids for the Bethany sewers in newspapers of major nearby cities also attracted bidders who did not witness the previously mentioned pilot contract. Therefore, an adequately advertised single demonstration pull was made of about 300 feet (91 m), simply to familiarize prospective bidders with the Badger technique. No changes were made in the equipment or alignment control.

The most significant advance in the vertical and horizontal control equipment for the Badger was introduced when the construction began in the South Bethany Sewer District. At this point, the laser receiver was directly wired to control the solenoid valves of the grading ram to automatically control the pipe invert elevation. The laser beam, rotating in a plane set to the design slope of the pipe, was initially geared to rotate at five revolutions per second. Each time the laser beam hit the sector of the receiver above or below the ongrade sector, it would trigger a pulse flow of hydraulic fluid to the grading ram.

Since this arrangement did not produce a suitably rapid correction in pipe invert elevation in relation to the Badger plow travel speed, the laser beam rotation was increased to ten revolutions per second. This modification apparently solved the problem because no further increases were made in the rotation speed of the laser beam used for vertical control.

This increased use of laser control was extended to improve horizontal alignment at the beginning of the South Bethany sewer construction. A second laser beam was added which was oscillating in a vertical plane offset from and parallel to the design alignment of the pipe. The two laser receivers, one fore and the other aft, were attached in a horizontal attitude at different heights with the "online" sectors of the receivers set the same distance from the center line of installation on the same side of the Badger machine. These laser receivers triggered indicator lights which the Badger operator used as a guide in steering the machine. The reason for setting the forward horizontal control receiver higher than the aft receiver was to prevent the aft receiver from interfering with the beam transmitting signals to the forward receiver. The other significant refinement needed for the laser control system involved its stability. Heavy equipment or vehicles moving near the tripod on which the laser transmitter was mounted disturbed its sensitive calibration. Moderately strong winds were also a problem as well as thermal expansion from the sun which moved the paving under the tripod. This problem was solved by the addition of an automatic leveling attachment to the laser transmitter.

SECTION 6

DESCRIPTION OF CONSTRUCTION

GENERAL

The trenchless method of sewer construction and, in particular the Badger system used for this project, involves many techniques which vary significantly from those used when sewers are installed conventionally. With the trenchless technique, site preparation, and dewatering are reduced to a minimum. The nature and size of project construction crews also differ significantly.

This chapter will provide a definition of personnel requirements, set forth the differences in the two construction techniques, describe improvements made to the Badger system during construction, provide a summary of technical data derived from records maintained by onsite inspectors and, finally, develop a tabulation of suggestions which may be incorporated by other designers interested in preparing plans and specifications for projects using the trenchless technique.

COMPARATIVE CONSTRUCTION TECHNIQUES (General)

Construction Crew Definition

The descriptions provided herein represent average crews used by the general and subcontractors on this particular project. They may vary significantly from one regional location to another depending upon contractor preferences, labor market variations, etc. Furthermore, the general contractor on this project employed three conventional pipe installation crews simultaneously, which provided him with the flexibility of sharing certain skilled labor crafts between the three crews.

The conventional crew was made up of a foreman, three heavy equipment operators, one pipe layer, three laborers, one engineer and one engineer's helper. The functions of individual personnel were as follows:

Foreman - Supervise Installation

Equipment Operators

Backhoe Operator (1) - Trenching
Front End Loader (1) - Site preparation and backfill
Dump Truck Operators (1)- Hauling select fill and gravel
and disposing of unsuitable
materials.

Pipe Layer - Inspection for suitability of grade,
and making joint connections.

Laborers

- Tailman (1) - For ramming home pipe.
- Others (2) - For carrying pipe, lubricating joints and tamping backfill.

- Engineer - To establish grade and alignment with laser equipment.

- Engineer's Helper - To assist engineer.

The Badger crew consisted of a foreman, two equipment operators and two laborers. The responsibilities of each individual were as follows:

- Foreman - Supervise construction, set up laser to establish grade and provide general instructions to trenchless sewer equipment operator.

Equipment Operators

- Trenchless (1) - Operate Badger equipment

- Backhoe/Front End Loader (1) - Dig lead trench, excavate for disconnection, backfill.

- Laborers (2) - To solvent weld pipe, string out, etc.

In both the conventional and trenchless areas, the same number of personnel were utilized for crews performing in the following construction activities:

Stakeout
Manhole Construction
Lateral Construction
Paving

Construction Elements

Stakeout--In both the conventional and the trenchless areas, stakeout was limited to establishing horizontal and vertical alignment at each future manhole location.

Site Preparation--The bulk of conventional and innovative sewer construction took place either in nonpaved shoulders or in areas where the paving was limited to surface treatment with asphalt and stone. In the conventional areas where surface treatment existed, site preparation consisted of removing this material with a front end loader and stockpiling it for future disposal. In the trenchless area, no site preparation was required.

Dewatering--As was noted in Section 4, a persistent high water table was encountered at all times during the construction period. Watertable depths varied between 0.5 feet and 2.5 feet (0.15 to 0.76 m) from grade. In the conventional area a system of wells was jetted into the water bearing strata on one side of the proposed sewer trench and connected with a header pipe and pump. Dewatering in the trenchless area was limited to the use of a submersible pump on two occasions for lead trenches.

Open Trenching--Because of the shallow nature of the sewers designed for the South Bethany Demonstration Project, a backhoe was suitable for open trenching, for mains and laterals with or without sheeting, in the conventional area. Excavated material was stock piled on one side of the trench. In the trenchless area, open trenching was required for the lead trench, for disconnecting the pipe after the pull and for saddle wye and lateral installation.

Foundation--In the conventional area, 0.5 feet (0.15 m) of Class I bedding material was to be provided for all PVC sewer. Class I was defined in the specifications as 1/4" to 3/4" (0.64 to 1.90 cm) angular graded stone, coral, slag, cinders, crushed stone or crushed shells. About midway through the project, this requirement was deleted except where unstable conditions such as mud or water were encountered. In the trenchless area, Class I bedding was provided on a limited basis to stabilize end of pipes when there were significant delays between pipe pull and manhole installation. In addition, bedding was sometimes used to stabilize the main sewer during open trenching for saddle installation and when conventional methods were used to complete the connection of Badger pipe to a manhole.

Pipe Installation--In general, in the conventional area, pipe was installed as outlined below. The work elements are presented in the order in which they took place.

1. Set up a laser for vertical and horizontal alignment.
2. Transfer of pipe to trench.
3. Clean bell and spigot.
4. Lubricate gasket.
5. Line up pipe and ram home.
6. Check alignment.
7. Tamped backfill in lifts.
8. Manhole installation.
9. Open trench for lateral connection to wye.
10. Backfill.
11. Paving.

In the trenchless area, the following steps were required for the installation of a complete sewer system. A more detailed descrip-

tion is provided later in the section.

1. Identify and stakeout utilities.
2. Lay out pipe.
3. Clean and solvent weld joints.
4. Drill hole in pipe.
5. Set up laser.
6. Excavate lead trench.
7. Position pull equipment and deadman if necessary.
8. Preplow.
9. String out pipe, within the construction easement, behind the trenchless installation equipment.
10. Connect pipe to expander.
11. Pull pipe.
12. Check elevations.
13. Excavate and disconnect the pipe.
14. Place gravel under disconnected pipe end.
15. Open cut for manholes and install.
16. Open cut for laterals.
17. Cut hole for saddle.
18. Apply solvent cement, allow for curing and install saddle.
19. Install lateral.
20. Repair utilities.
21. Paving.

The utility repair took place in a sequence which was dependent upon the urgency of facilitating the repair.

THE BADGER SYSTEM (Specifics)

The Badger foreman and the operator of the trenchless equipment are specially trained individuals who must be intimately familiar with the trenchless technique. The backhoe operator and the two laborers, which make up the balance of the crew, need no additional skills beyond those required for conventional construction.

The two laborers act as a unit almost independent of the other three individuals of the crew. Their main responsibility is to insure that sufficient solvent welded pipe is available to the trenchless crew for each pull. Their work, which takes place simultaneously with that of the Badger crew, involves no unique skills and, therefore, requires no further discussion.

Figure 7 (page 19) provides a plan view of the Badger system which supports the following narrative.

While the labor crew is solvent welding and stringing out sufficient pipe to meet daily requirements, the Badger unit is brought into approximate alignment. If the foreman anticipates traction problems, a deadman

is located approximately thirty feet (9.14 m) beyond the end of the pull to allow room for the Badger once the pull is completed, see Figure 8.

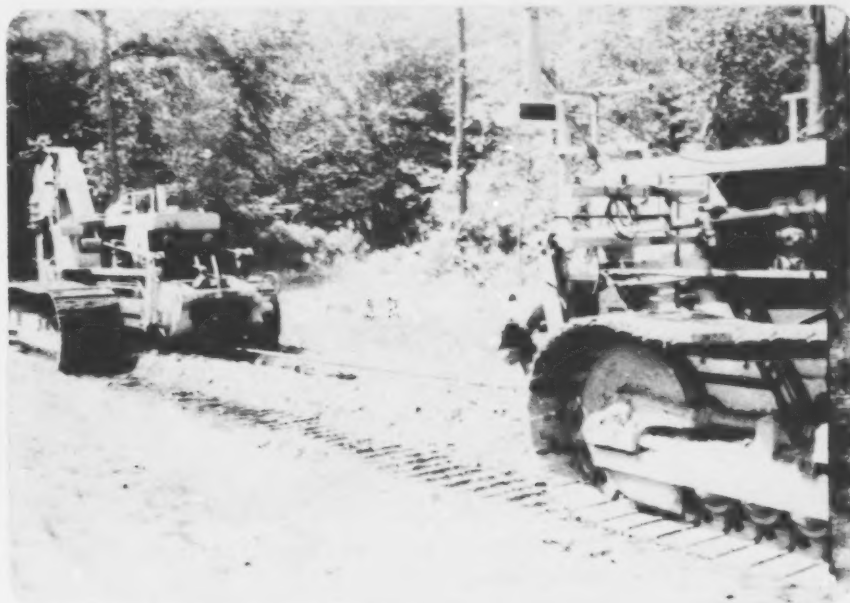


Figure 8. Badger Minor with winch attached.

The foreman then sets up the laser approximately 6.5 feet (1.98 m) off the centerline of the proposed sewer line, which is the approximate distance between the center of pipe and the outboard receivers on the Badger Minor. The laser receiver is shown on Figure 9. The Badger operator assists the foreman in adjusting the laser to the appropriate slope and establishing invert elevations. Using a stadia rod, laser receiver and transceiver at the far end of the pull, the operator communicates with the foreman who remains at the laser and makes the required corrections until the desired slope is achieved, see Figure 10.

When using the trenchless method, care must be taken to avoid undue stresses in the pipe as it is being pulled into the ground. To minimize these stresses, a lead trench was constructed, the length of which was to increase in direct proportion to the depth of cut. The width of such trench is dependent upon the diameter of the pipe and the equipment used to offset the uplifting tendency of the pulled pipe.

The plow, without the pipe being connected, was routinely pulled along the sewer route prior to an actual pull sequence. The Badger equipment operator normally required at least one preplow subsequent to

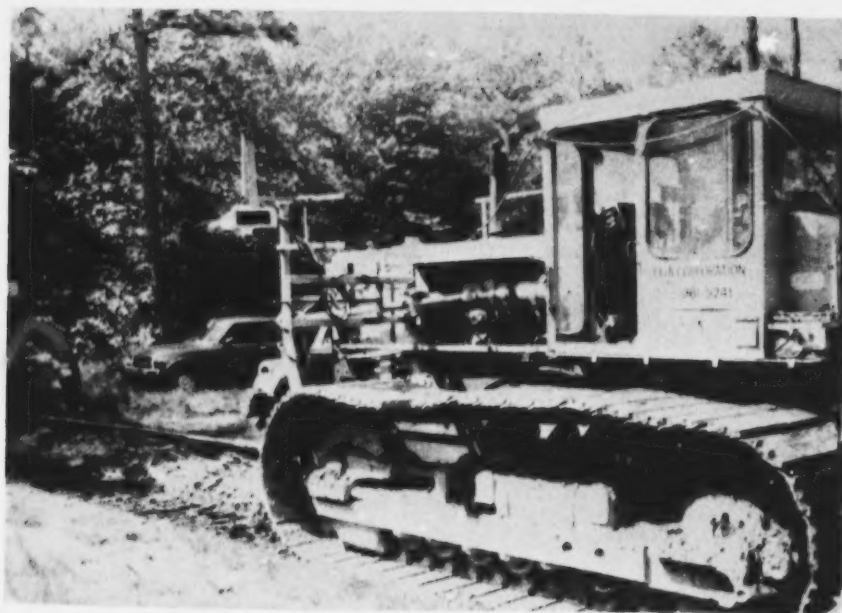


Figure 9. Outboard Laser receiver for horizontal alignment.



Figure 10. Badger foreman and operator setting grade and horizontal alignment.

the actual installation of pipe for the following stated reasons:

1. To remove any subsurface obstacles in the path of the plow.
2. To equalize ground pressure and reduce drag on the pipe.
3. To insure maintenance of horizontal and vertical alignment during the pull.

More than one preplow was required depending upon the depth of the plow and the hardness of the ground being plowed. The number of pre-plows required is totally dependent upon operator judgment. Before or during the preplow, the pipe is laid out behind the point of insertion. Figure 11 shows a length of pipe extending into a marsh, over a manhole and then into the lead trench.

Once the preplows are completed, a coupling is connected to the predrilled pipe and it is dragged forward for insertion in the expander, see Figure 12. Connection is accomplished simply by placing a pin through the expander and the hole in the coupling and inserting a removable clip in the end of the pin. The operator selects the expander size based on the ground conditions encountered. In cohesive soils, one uses an expander with a diameter closer to the size of the pipe being pulled to prevent floating of the pipe in the hole created by the expander. A final check of laser equipment is performed by the foreman prior to his authorizing the pull.

The plow blade, with pipe connected, is lowered into the trench whereupon the backhoe operator lowers the bucket onto the pipe. Refer to Figures 13, 14, 15, 16 and 17 for a pictorial sequence of these operations. The bucket has rollers connected to the base so as not to damage the pipe while still preventing uplifting.

After the pipe has been pulled through the trench, Figure 18, and the expander reaches the point at which the next manhole will be located, the pipe is backed into the lead trench manhole, see Figure 19. The success of the pull is determined by checking the invert elevation of the pipe using a point on the linkage which is at a predetermined distance from the invert. If the elevation is within the specified tolerance, the foreman authorizes excavation of the pipe to allow disconnection of the pipe from the Badger expander, see Figure 20. Prior to backfilling, stone is placed under the pipe to provide suitable bedding to insure that the elevation will be maintained until the manhole installation crew arrives.

If the tolerance is not met, and field conditions allow, the foreman can instruct the operator to pull the sewer out. In cohesive soils, care must be taken to reach a decision promptly, otherwise the soil friction resulting from stabilization of the expanded pipe tunnel may preclude removal. If this occurs, the operator may disconnect and plow through the off-grade pipe.

Saddle wyes are installed at a later date by open cutting at the approximate lateral location, dewatering if required, cutting a hole in



Figure 11. Pipe extending into marsh prior to pull.



Figure 12. Insertion of pipe into expander.



Figure 13. Pipe connected prior to lowering into lead trench.



Figure 14. Pipe and plow in lead trench (Plan View).



Figure 15. Pipe and plow in lead trench.

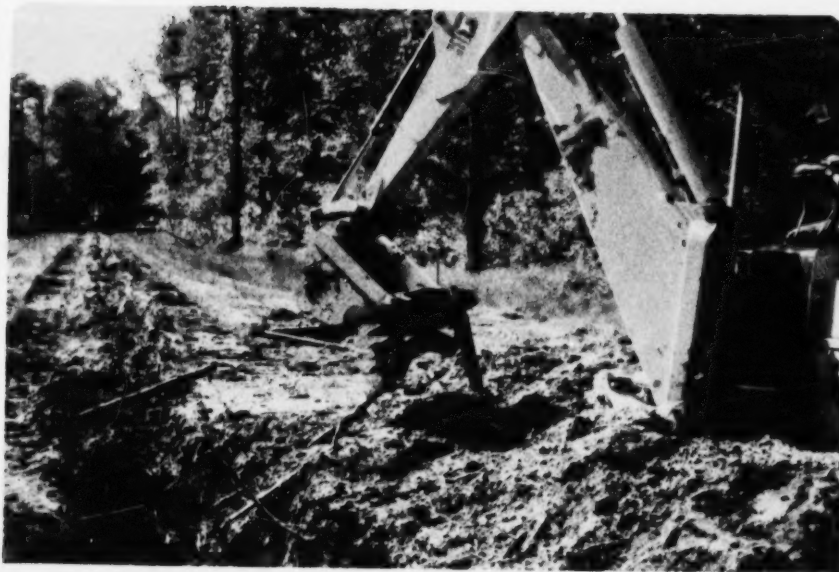


Figure 16. Bucket with rollers for vertical stabilization of pipe.



Figure 17. Bucket with rollers in place.



Figure 18. Plow sequence in progress.



Figure 19. Backing into manhole provides stress relief and final connection.



Figure 20. Excavation at end of pull.

the pipe, cleaning and drying the pipe, applying the solvent, strapping on the saddle and allowing for the appropriate curing time before backfill. In the majority of lateral installations, dewatering was not required. The remaining construction activities, such as installation of laterals and repaving, required techniques which duplicated those of conventional construction.

TECHNIQUE IMPROVEMENTS

There were many problems encountered during the development stage, which preceeded actual construction, and also during the construction phase. Sufficient doubts were raised about the new system so that the contract specifications included a performance clause as follows:

- A. "The purpose of a performance contract is to determine if the contractor with the lowest bid electing to use the innovative method of sewer construction can demonstrate that he is capable of complying with the requirements of these specifications. The demonstration shall consist of actual sewer construction using the innovative method."
- B. "The performance contract shall utilize the innovative method exclusively. A minimum of 1500 lineal feet of eight inch (8") sewer main, manholes, 6" connections, complete with all restoration and testing shall be constructed within the project limits at a location chosen by the contractor and approved by the engineer."
- C. "If, at the completion of this performance contract, the contractor has not satisfactorily accomplished installation of sewers by the innovative method as determined by the specifications and interpreted by the engineer, the remaining part of the contract shall be completed by the conventional method of sewer installation."

There were significant deviations between the design and actual invert elevations on most of the sewer lines installed under the performance contract. However, the installation by the contractor was deemed adequate for the following reasons;

- A. All lines were lamped and at least three quarters of the barrel was observed in each line.
- B. No infiltration was observed in any of the lines.
- C. The hydraulic capacity of all sections was adequate for the anticipated flow in each line.
- D. With the exception of 342 lineal feet (104 m), the full pipe velocities were always in excess of two feet per second (.69 m/sec) as determined using an "n" value of 0.011.

A summary of problems encountered during the entire project and solutions derived is presented below.

Problem

Stresses in the pipe caused an uplifting of the pipe for approximately twenty feet past the lead trench in the direction of the pull.

Solution

The first attempt to solve the problem was by increasing the length of the lead trench in order to reduce the downward slope as the pipe entered the expander tunnel. Although partially successful, dewatering was used in the next attempt as it was felt that the buoyancy factor which remained after stress relieving of the pipe may have been significant enough to cause the uplifting. This modification proved unsatisfactory. The problem was finally resolved by installing rollers on a backhoe bucket and applying a uniform pressure to the pipe as it was pulled. This method was used for the rest of the project and was instrumental in the successful operation of the innovative method.

Problem

The laser beam was unable to maintain grade when temperature changes caused creep in the surface on which the tripod was mounted.

Solution

The laser was modified by installing an automatic leveling device.

Problem

The laser became unstable in high winds and the operator was unable to control vertical and horizontal alignment.

Solution

The subcontractor attempted to erect a temporary windshield, but this device did not prevent instability. The laser manufacturer suggested that a new clutch assembly would resolve the problem. Such a system was installed. No problems were encountered thereafter.

Problem

Ends of pipe did not meet invert elevations when manholes were placed.

Solution

Stone bedding was placed underneath the pipe to stabilize the foundation and manhole crews were instructed to begin constructing manholes promptly after the completion of a pull.

Problem

During the development stage, one of the sewer pipes cracked when an attempt was made to cut a hole so a saddle could be welded to the pipe.

Solution

The tensile forces built up in the pipe were relieved by moving the Badger unit backwards thereby relieving the tension.

Problem

When the contractor moved in and opened a trench to allow for saddle and lateral installation, the unsupported pipe tended to move both vertically and horizontally.

Solution

After undercutting the pipe, a stone bed was provided. This system was only moderately successfully and the reader is referred to the "Design and Construction Management Notes" portion of this Section for suggested improvements to this procedure.

Problem

In clay seams, the pipe tended to float apparently because the cohesive soil remained open for a substantial period after the pull had been completed.

Solution

The operator selected a smaller diameter expander to reduce the size of the pull hole.

Problem

One of the sewers was plowed in off grade in an area where manmade lagoons precluded pulling the sewer out.

Solution

The Badger operator plowed through the pipe and, after having made two passes, plowed in a new pipe to replace the one destroyed.

Problem

In areas where utilities, perpendicular to the path of the Badger, could not be cut by the Badger for safety reasons the cost of open trenching past the utility and then installing sewer by conventional means was deemed to be excessive.

Solution

The contractor open trenched between the manhole and the utility and the open trench was used as a lead trench for the Badger.

PROJECT RECORDS AND DATA

During the performance phase of construction, record keeping by field inspectors was generally limited to maintaining standard inspection forms and providing narrative descriptions of problems encountered and solutions developed. This phase of the work covered approximately two calendar months beginning in January 1976 and ending March 1, 1976. During this period approximately 15% of the total lineal footage ultimately installed by the trenchless method was constructed. The months of March, April and May were periods of active construction after the trenchless technique had been refined.

To provide for an accurate data base during this latter construction phase, a field observation inspection form was developed, see Exhibit 1. The basic format was developed in draft form and the attached exhibit represents the final form resulting from recommendations by the field inspector. Approximately 85% of project construction is covered by information developed in accordance with this form. Records were kept in four key categories: General; Prepull; Pull; and Post Pull.

Rates For Various Work Tasks

As noted in the field observation form, a great deal of the information related to time studies. This information was developed not only to determine average rates for the entire project, but also to see if there was a marked improvement in certain work task categories as the project continued. The latter was expected in view of the fact that, as a demonstration project, a certain period of time at the outset would be required to develop the technique.

Project Averages--

Eighty pulls were required to install approximately 23,000 lineal feet (7010 meters) of 8" (20.3 cm) solvent welded PVC gravity sewer pipe. Referring to Table 2, the average pull was approximately 285 lineal feet

4/28

Pull # 2

Utilities Cut: Type None Sta. 0

Comments:

Other Activity

Personnel # Manhours

Equipment

Equipment Hours

Obstacles Removed (Description and Sketch) Attachment Yes No
Estimated elapsed total preparation time 2 hr.

III. Pull

Pull time 7 min. Dechen used? Yes No

Pull uneventful? Yes No If no explain in General Comments.

IV. Post Pull

Backup? Yes No Distance plow moved 1 in.

Distance end of pipe moved (Lead Trench) 1 in.

Soil between pipe and sewer plug? Yes No

Slopes, Elevations

Mile for sta.	Invert Elev. (ft)	Slope (ft/ft)	
		Design	Actual
MI 4 or sta. 2A11C (9417)	-1.94	0.0028	
" " " 9417	-1.94	-1.9070	0.0028612
" " " 5471	-2.90	-2.89	

Method used to restore utility services:

Pull # 2
Date 4/28/76 Air Temp. 51 PM By John Russell
Weather Clear, Cool & Windy

I. General

Street New Castle Dr.
Pull from MI 2A11C (9417) to MI 2A11B (555D)
Lengths Design 358 LF Actual 346 LF
Personnel: ✓ Men and Monitors 2 Laborers 1 Operators 0 Other
Equipment: ✓ Full Badger ✓ Anchor Badger ✓ Comb. Loader

II. Pre-Pull

Pipe Preparation Personnel 2 # Manhours 1 LF
Laser setup and Establishing Inverts Personnel 2 # Manhours 1.5

Methods: Once laser is level, elevation readings are taken on the 20' offset hubs with a specially equipped elevation rod. Using these readings and information from cut sheets the height of the Badger grade receiver is computed and then the receiver is adjusted accordingly. See General Comments for change in procedure.

Dry Run # of pulls without pipe 2

Lead Trenches Dewatered? Yes No Water Level 0.30 ft.

Soils	Type	Depth	Type	Depth
1. <u>Appld. Form</u>			4.	
2. <u>Subsoil</u>			5.	
3. <u>Separation</u>			6.	

Dimensions:

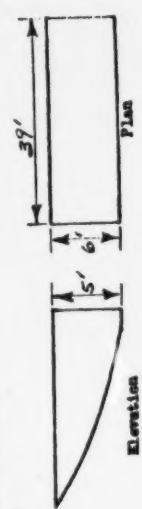


TABLE 2

Rate Data

Project Averages

	#of Pulls	Laser Setup Hours	Total Preparation Hours	Pull Time Minutes	Pipe Installed	
					Feet	Meters
Total	80.0	63.25	153.04	595.0	22,942.0	6,992.7
Weekly Average	7.3	5.75	13.91	54.1	2,085.6	635.7
Daily Average	1.46	1.15	2.78	10.82	417.1	127.1
Pull Day Avg.	1.74	1.38	3.33	12.93	498.7	152.0
Average per pull	1.0	0.78	1.90	7.41	285.7	87.1
Hourly Avg.	0.18	0.14	0.35	1.35	52.1	15.9

*Excluding solvent welding and stringout.

(87 meters) and required less than 7 1/2 minutes actual installation time. The total preparation time, 1.9 hours, excludes the time required for solvent welding and stringing out the pipe which was to be pulled. The daily averages are based on a five day work week and differ from pull day averages in that the latter reflects only those days on which actual trenchless installation occurred.

The general information in Table 3 provides an overall picture of work task averages during the peak production period but does not adequately reflect rate trends as the Badger crew became more familiar with site conditions and adjusted their construction techniques accordingly. Referring to Table 3, monthly averages for the same work tasks and project rates were developed in order to determine whether or not efficiencies actually did increase. The time required to set up laser equipment was reduced from .98 hours in March to .69 hours in May. The total preparation time, exclusive of solvent welding and stringout, also showed a significant improvement, being reduced from 2.22 hours at the outset to 1.54 hours during the last month of construction activity. The average pull time also decreased, but this was responsive more to the fact that the average length of pull decreased from 314 to 288 lineal feet (95.7 to 87.8 m). The rate of installation in lineal feet per minute, i.e. the forward speed of the Badger, remained approximately constant at 39 feet per minute (11.9 m/min). Perhaps one of the most significant factors in reducing total preparation time was the fact that the subcontractor attempted to plan his work so as to utilize the same laser position and same excavations for two pulls.

The average lineal feet installed per day, based on a five day week, increased from 384 lineal feet per day to 480 lineal feet per day (117.0 to 146.3 m per day). Pull day improvements were also seen with an increase from 460 lineal feet per day, on days on which the Badger was operational, to 524 lineal feet per pull day at the end of the project (140.2 to 159.7 m per day). This is particularly significant in view of the reduction of length for each pull as construction progressed.

Solvent Welding and String Out--

During the course of the project it became evident that, with the limited number of inspectors available, it was virtually impossible to oversee all construction activities related to the Badger method. Time records and production rates for the two laborers assigned to welding and laying out the solvent weld pipe were kept for a four week period. Solvent welding rates varied between 204 lineal feet (62 m) per hour to 620 lineal feet (189 m) per hour with the average being 361 lineal feet (110 m) per hour. The string out times ranged between 325 lineal feet (99 m) per hour and 1200 lineal feet (366 m) per hour with the average being 650 lineal feet (198 m) per hour. No pattern or trend was discernable in either case. However, it should be noted that the lower layout rates in most instances were caused by natural and manmade obstacles which hindered the crew from placing the pipe.

TABLE 3

Rate Data

	# of Pulls	Monthly Averages				Pipe Installed	
		Laser Setup	Total Preparation	Pull Time	Feet	Meters	
		Hours	Hours	Minutes			
March							
Total	22	21.09	48.94	188	6,907	2,105.3	
Daily Avg.	1.2	1.17	2.72	10.44	384	117.0	
Pull Day Avg.	1.5	1.41	3.26	12.53	460	140.2	
Avg./Pull	1.0	.98	2.22	8.54	314	95.7	
April							
Total	38	28.41	73.35	260	10,269	3,130.0	
Daily Avg.	1.7	1.29	3.33	11.82	467	142.3	
Pull Day Avg.	1.9	1.42	3.66	13.0	513	156.4	
Avg./Pull	1.0	.75	1.93	6.84	280	85.3	
May							
Total	20	13.75	30.75	147	5,766	1,757.5	
Daily Avg.	1.7	1.15	2.56	12.25	480	146.3	
Pull Day Avg.	1.8	1.25	2.80	13.36	524	159.7	
Avg./Pull	1.0	.69	1.54	7.35	288	87.8	

Prepull Averages--

As noted previously, operator judgment determined the need for more than one prepull to prepare the subsoil for pipe installation. Based on inspection reports, the average number of preplows per pull required was 1.3 with the maximum being 4. No prepull was conducted in less than one percent of the cases.

Lead Trench Dimensions--

Due to concern over the possibility of pipe fracture during the prepull, the pipe manufacturer was required to provide optimum length to depth dimensions for the lead trench prior to the initiation of construction. These dimensions are shown in Table 4. Accurate records

TABLE 4

Pipe Manufacturer's Lead

Trench Dimension Recommendations

Depth of Cover		Trench Length	
Feet	Meters	Feet	Meters
1.0	.305	12.6	3.84
2.0	.610	17.7	5.40
3.0	.915	21.7	6.62
4.0	1.220	25.0	7.63
5.0	1.525	27.9	8.51
6.0	1.830	30.4	9.27
7.0	2.135	32.8	10.00
8.0	2.440	34.9	10.64
9.0	2.745	36.9	11.25
10.0	3.050	38.8	11.83

of actual field dimensions were maintained and the data is depicted in Figure 21. It is apparent from the lack of consolidation of the data that no trend developed under actual field conditions. In many cases, lead trench dimensions were minimized in order to reduce repaving costs. However, in no instance was a pipe fracture developed due to bending.

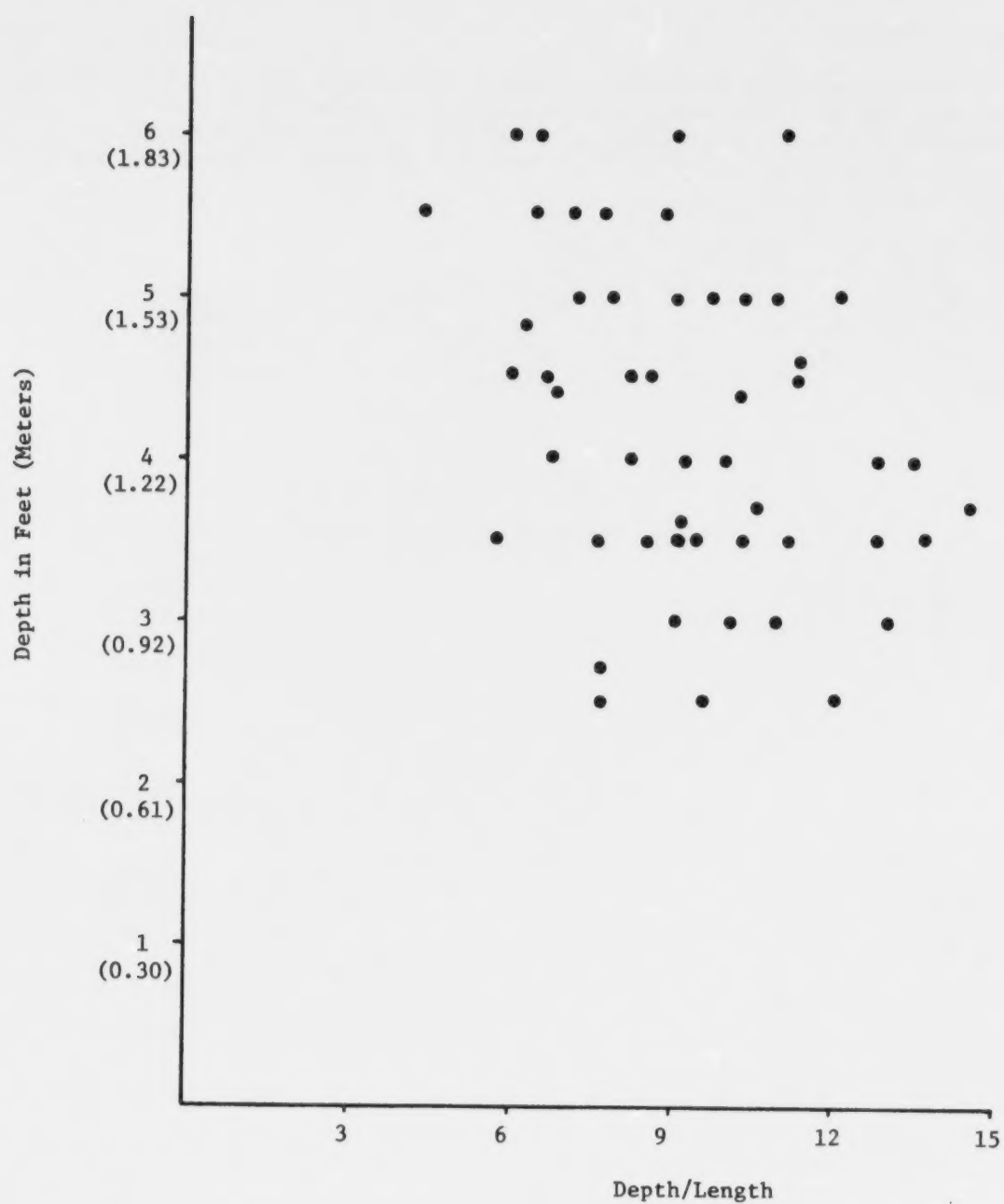


Figure 21 Lead Trench Dimensions, Depth versus ratio of Depth to Length

Pull Lengths

The actual construction rates were significantly affected by the short pull lengths associated with the South Bethany site. Referring to Table 5, note that 96% of the pulls were 400 feet (122 m) or less with greater than 50% being 300 feet (91.5 m) or less. By reviewing the previous information, it is obvious that longer pulls increased time requirements in only two significant work categories, i.e. solvent welding and string out. One can conclude, therefore, that had there been more pulls in the 500 to 600 feet (152.5 to 183 m) range, the rate of production would have been significantly improved.

Factors Relating to the Substitution of Conventional for Trenchless Method

Twelve hundred and seventy three feet (388 m) of gravity sewer pipe which was scheduled to be installed by the trenchless method was ultimately installed conventionally. Table 6 provides a tabulation of reduced installation amounts in four categories:

1. Physical Obstacles.
2. Pipe Length too Short
3. Solvent Weld Break.
4. Manhole Position Moved.

Approximately 67% of reduction was in the category related to physical obstacles. The bulk of these obstacles, such as houses, gardens, bulk heads, waterways were apparent without excavation and reduction in this category could be minimized in future design projects.

Only 4% of the loss was related to the welded pipe length being shorter than required.

The next major category constituted 17% of the loss and was related to manholes being repositioned during construction.

It is significant to note that only 12% of the loss was related to the failure of the solvent welded joint and that this percentage relates to only two weld failures. Upon inspection, it was confirmed that these failures were caused by poor workmanship.

DESIGN AND CONSTRUCTION MANAGEMENT NOTES

The following reference material is specific to gravity sewer installation by the trenchless technique but may be applicable to the installation of other utilities such as water mains, sewage force mains and utility conduits.

Contract Documents

The key to maximizing the benefits of the trenchless technique

TABLE 5

Range Feet (Meters)	Number of Pulls	Pull Lengths			Maximum Length Feet (Meters)
		Average Length Feet (Meters)	Minimum Length Feet (Meters)		
0 - 100 (0 - 30.5)	3	93 (28.3)	80 (24.4)		100 (30.5)
100 - 200 (30.5 - 61.0)	8	176 (53.6)	143 (43.6)		200 (61.0)
200 - 300 (61.0 - 91.5)	29	263 (80.2)	207 (63.1)		300 (91.5)
300 - 400 (91.5 - 122.0)	36	338 (103.0)	310 (94.5)		385 (117.3)
400 - 500 (122.0 - 152.5)	2	450 (137.2)	404 (123.1)		495 (150.9)
500 - 600 (152.5 - 183.0)	1	N/A -	N/A -		528 (160.9)
Length of Pull Feet (Meters)	Number of Pulls less than or equal to*		Percentage of Pulls Less than or equal to		
100 (30.5)	3				4
200 (61.0)	11				14
300 (91.5)	40				51
400 (122.0)	76				96
500 (152.5)	78				99
600 (183.0)	79				100

*One pull not completed.

TABLE 6

Summary of Footage Lost to Trenchless Method

PHYSICAL OBSTACLES

<u>Length Lost</u> <u>Feet</u>	<u>Remarks</u>	<u>Length Lost</u> <u>Feet</u>	<u>Remarks</u>
10	M.H. close to bulkhead	12	M.H. close to house
10	M.H. close to bulkhead	4	M.H. close to bulkhead
3	M.H. close to canal	22	Ground too rough
32	Unable to winch on Route 14	38	900 pair cable in way
5	M.H. close to bulkhead	40	" " " " "
40	Unable to winch on Route 14	22	Ground too rough
55	" " " " " "	14	M.H. close to canal
65	M.H. close to house	76	900 pair cable in way
45	House in way of winch	27	Ground too rough
20	M.H. close to house	40	M.H. close to canal
25	" " " "	15	" " " "
25	M.H. close to gardens	21	" " " "
25	Ground too rough to finish	18	" " " "
20	M.H. close to bulkhead	19	" " " "
20	M.H. close to gardens	21	" " " "
20	Phone cable in way	24	" " " "
		<u>16</u>	M.H. close to woods
	Subtotal	849	(258.8 m)

PIPE LENGTH TOO SHORT

6	Pipe jointed short	5	Pipe jointed short
4	Pipe jointed short	10	Pipe jointed short
5	Pipe jointed short	6	Pipe jointed short
5	Pipe jointed short	5	Pipe jointed short
5	Pipe jointed short	<u>1</u>	Pipe jointed short
	Subtotal	52	(15.8 m)

SOLVENT WELD BREAK

45	Pipe joint pulled out	<u>105</u>	Pipe joint pulled out
	Subtotal	150	(45.7 m)

MANHOLE POSITION MOVED

60	M.H. position moved	10	Pulled to existing M.H.
36	M.H. position moved	12	Pulled to existing M.H.
40	M.H. position moved	12	Pulled to existing M.H.
6	Pulled to existing M.H.	20	Pulled to existing M.H.
		<u>26</u>	Pulled to existing M.H.
	Subtotal	222	(67.7 m)
	TOTAL	1,273	(388.0 m)

is to take particular care in establishing vertical and horizontal alignment with relation to surface and subsurface objects to avoid hindering the production rate or, in extreme cases, requiring the substitution of conventional techniques. The information provided herein will be useful to the designer contemplating the use of the technique for the first time.

If using photogrammetric layouts, approximate locations of surface objects should be field verified and, in cases where either construction easements for pipe layout is required or where the Badger system may induce mobility problems, dimensions should be verified in the field with reasonable accuracy. If space is critical, the trenchless technique is normally adaptable to twenty feet (6.1 m) for construction easement (centered on the sewer) and ten feet (3.05 m) for pipe layout easement.

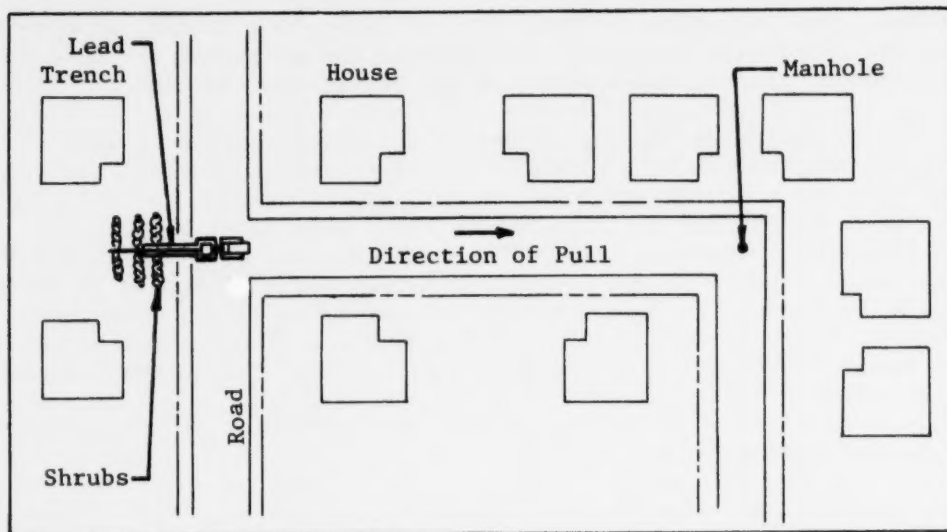
Existing subsurface utilities and other structures should be noted in the drawings in detail where possible. Knowledge of their location may, in some cases, allow the designer to parallel these utilities and avoid substitution of the more costly conventional method where a utility crossing could have been avoided.

Where the flexibility exists, the designer should maximize the length of pull preceeding a change in direction so as to decrease the preparation time per lineal feet of sewer installed. As noted previously, significant savings can be accrued by minimizing the number of manhours consumed in positioning the laser, opening the lead trench, etc.

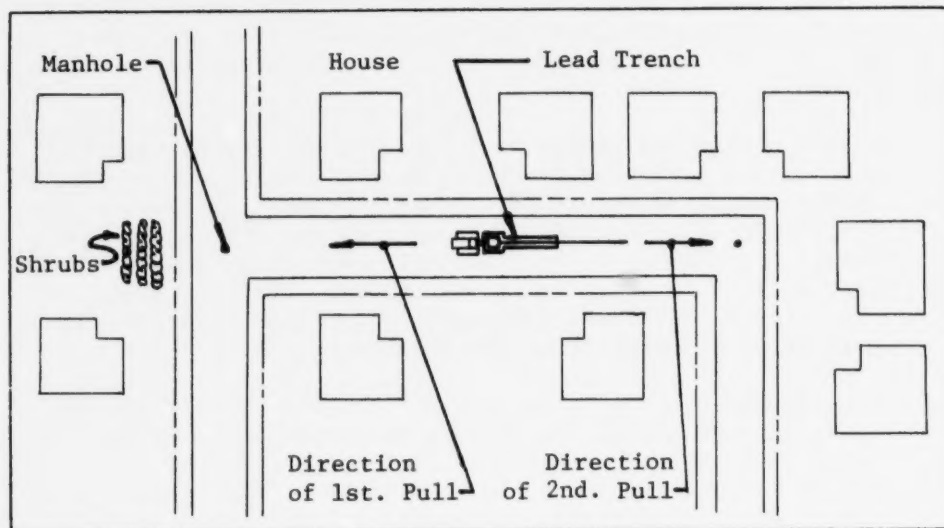
The designer may avoid costly delays and a possible request for extra payment by checking potential lead trench positions with relation to construction easement problems. As an example, referring to Figure 22, Alternate A, it is apparent that the individual on whose property the lead trench might be placed may voice significant objection toward the removal of shrubs identified in the topography. If this construction easement cannot be obtained, as shown in Alternate B, the contractor may have to center the lead trench where he can pull half a length in each direction. The specification should identify this as an alternate technique available to the contractor which, if employed, will be done at no additional expense to the Owner.

In a grass roots project where a number of utilities are to be installed using the trenchless technique, under the same contract, the designer should position manholes in such a manner as to allow the lead trench for the Badger pull to serve for more than one utility.

Under the subsection Technique Improvements, a number of problems and corrective actions were identified. On the basis of the experience derived during this project, it would appear that specifications for the trenchless technique require cautionary instructions which are unique to



ALTERNATE A



ALTERNATE B

Figure 22 Method used to overcome easement problem

the method. The inclusion of these instructions, in a wording acceptable to the particular designer, will provide the necessary latitude to the resident project representative for protecting the owner.

Prior to reviewing those portions of the specifications which are particularly useful to the resident project representative, there are two items of a design nature which will be discussed. The PVC pipe specified for trenchless installation for this particular project was ASTM D-3033 SDR 41 whereas the gravity sewer pipe was ASTM D-3034 SDR 35. The solvent weld pipe for the trenchless method had a minimum wall thickness of 0.199 inches (.505 cm) whereas for the conventional sewer the minimum wall thickness was 0.240 inches (.609 cm). The thicker material was unavailable with solvent weld joints at the time the contract documents were advertised. However, based on field observations, it was felt that a thicker wall pipe would reduce vertical and horizontal displacement problems created during lateral installation.

The manhole pipe seals used on this project were particularly adaptable to the stress relief system which will be discussed later in this subsection. The precast manholes utilized integrally cast A-LOK gaskets per ASTM Rubber Gasket Specification C-443.

The following construction guidelines are, for convenience, listed in the order in which they would be used during construction:

1. Do not allow solvent welding of joints when temperatures are less than 40 degrees fahrenheit. Adhere to the pipe manufacturer's recommendations when pulling welded material during cold weather.
2. Once the pipe has been pulled, require the Badger operator to back the equipment in the reverse direction for a minimum of two inches to reduce pipe tensile stress. This back-up procedure, of course, is to be performed while the pipe is still connected to the expander and must be done promptly, particularly in cohesive soils. Require the contractor to check the elevation at the Badger end of the pipe after each pull prior to backfilling the excavation.
3. Require the contractor to provide suitable support for the sewer at each end of the pipe to maintain invert control prior to manhole installation. A stone bedding to the spring line or a brace would be suitable. The method should not be specified, but should be subject to the engineer's approval prior to use.
4. When opening the trench to make saddle and lateral connections, the contractor should be required to stabilize the exposed sewer pipe. Once again, although the method need not be

specified, it should be subject to the engineer's approval prior to actual saddle installation. Two methods which appear to be practical are the placement of stone bedding to the spring line after undercutting the pipe or; the placement of a wood or rebar brace which can be left in place after lateral installation.

In grass roots projects, the construction of buildings, culverts, etc. should be closely coordinated with the installation of the utility being installed by the trenchless method.

SECTION 7

PROJECT EVALUATION

EVALUATION GOALS

The principal purposes of this project were to first develop and then evaluate cost, performance and effectiveness data with relation to both the conventional and trenchless technique under similar site conditions. Cost comparison methods used were as follows:

- Contract Prices
- Calculated Composite Sewer Systems
- Man-day Rate

In addition, certain environmental factors were to be considered with primary emphasis placed on the possible impact on groundwater quality. Other environmental factors considered in this report resulted from observations of the trenchless technique and were actually considered in retrospect. Therefore, quantitative data on environmental factors, with the exception of groundwater quality, was not developed.

COST COMPARISON

Contract Prices

Tables 7 and 8 present actual contract price data (i.e. low bid unit prices) for selected elements of the contract for both the conventional and innovative portions of the work. Unit costs are shown only for those items which are normally considered to be directly related to each of the systems.

The unit costs for eight inch (20.3 cm) PVC gravity sewer main for conventional and trenchless areas were \$15 and \$9 per lineal foot (\$49.21/m and \$29.53/m), respectively. Unit prices for wyes, manholes, repaving, stone bedding, etc. were equal for both techniques. The bid elements for the innovative area, however, included certain elements unique to the Badger System; repair to underground utility services and storm drains; and, a significant bid item of \$62,000 for mobilization, demobilization. In addition, a unit price was provided for sewer installation with conventional techniques where linkage between Badger pipe and a manhole was required for reasons previously discussed.

These contract prices may not truly reflect the actual cost of construction but do provide the base prices with which one can anticipate the possible cost differential between the use of either system. Two other methods of cost comparison developed to provide both consultant and contractor with alternate techniques to assess potential cost savings for a particular situation are presented in the ensuing portions of this section.

TABLE 7

CONTRACT PRICES FOR CONVENTIONAL PORTION OF
THE SOUTH BETHANY DEMONSTRATION PROJECT

<u>Description of Item</u>	<u>Unit Cost</u>	<u>Quantity</u>	<u>Total Cost</u>
For furnishing and placing, complete in place, except road resurfacing, Sanitary Sewer Gravity Mains per Plans and Specs. 8" PVC	\$ 15.00/LF (\$49.21/m)	29,691 LF (9,050 m)	\$445,365.00
For furnishing and placing complete in place except road resurfacing Sanitary Sewer Gravity Mains without stone 8" PVC	\$ 14.85/LF (\$48.72/m)	7,676 LF (2,340 m)	113,988.60
For furnishing and placing complete in place Wye Branch. 8" x 6" PVC	\$ 60.00 Ea.	494	29,640.00
For furnishing and placing standard manhole per plans and specs. Manhole under 4 feet Manhole under 6 feet Manhole under 8 feet	\$ 500.00 Ea. \$ 510.00 Ea. \$ 600.00 Ea.	35 27 27	17,500.00 13,770.00 16,200.00
For furnishing grade F select borrow complete in place as required.	\$ 1.50/Cu.Yd. (\$1.96/Cu.M)	14,909 Cu.Yd. (11,405 Cu.M)	22,363.50
For furnishing and placing contingent stone bedding.	\$ 8.00/Cu.Yd. (\$10.46/Cu.M)	418 Cu.Yd. (320 Cu.M)	3,344.00
For furnishing and placing tar and chip Bituminous surface treatment	\$ 1.50/Sq.Yd. (\$1.79/Sq.M)	20,730 Sq.Yd. (17,330 Sq.M)	31,095.00
For furnishing and placing Bituminous Hot Mix surface per plans and specs.	\$ 7.00/Sq.Yd. (\$8.37/Sq.M)	5,452 Sq.Yd. (4,558 Sq.M)	38,164.00

TABLE 8

CONTRACT PRICES FOR INNOVATIVE PORTION OF
THE SOUTH BETHANY DEMONSTRATION PROJECT

<u>Description of Item</u>	<u>Unit Cost</u>	<u>Quantity</u>	<u>Total Cost</u>
For furnishing and placing complete in place, except road resurfacing, Sanitary Sewer Gravity Mains per Plans and Specs. 8" PVC	\$ 15.00/LF (\$49.21/m)	2,287 LF (697/m)	\$ 34,305.00
8" PVC (Badger)	\$ 9.00/LF (\$29.53/m)	26,764 LF (8,158 m)	204,876.00
For furnishing and placing complete in place except road resurfacing, sanitary sewer gravity mains without stone 8" PVC	\$ 14.85/LF (\$48.72/m)	2,669.5 LG (814.2 m)	39,642.08
For furnishing and placing complete in place, except road resurfacing 6" Sanitary Sewer Laterals to property lines per plans and specs.	\$ 5.00/LF (\$16.40/m)	26,265 LF (8,006 m)	131,325.00
For furnishing and placing complete in place Wye Branches 8" x 6" PVC	\$ 60.00/Ea.	822	49,320.00
For furnishing and placing Standard Manhole Plans and Specs.			
Manhole under 4 feet	\$500.00/Ea.	78	39,000.00
Manhole under 6 feet	\$510.00/Ea.	42	21,420.00
Manhole under 8 feet	\$600.00/Ea.	11	6,600.00

Table 8 (Continued)

<u>Description of Item</u>	<u>Unit Cost</u>	<u>Quantity</u>	<u>Total Cost</u>
For furnishing and placing contingent stone bedding	\$ 8.00/Cu.Yd. (\$10.46/Cu.m)	502.5 Cu.Yd. (384.4 Cu.m)	\$ 4,020.00
For contingent excavation as required	\$ 2.00/Cu.Yd. (\$2.61/Cu.m)	429.5 Cu.Yd. (328.6 Cu.m)	859.00
For furnishing and placing contingent crusher run base course completed in place as required.	\$ 20.00/Cu.Yd. (\$26.14/Cu.m)	133 Cu.Yd. (102 Cu.m)	2,660.00
For furnishing and placing tar and chip Bituminous surface treatment for plans and specs.	\$ 1.50/Sq.Yd. (\$1.79/Sq.m)	39,627 Sq.Yd. (33,128 Sq.m)	59,440.50
For furnishing and placing Bituminous Hot Mix surface per plans and specs.	\$ 7.00/Sq.Yd. (\$8.37/Sq.m)	174.7 Sq.Yd. (146.0 Sq.m)	1,222.90
Underground cable TV house services	\$125.00/Ea.	2	250.00
Underground telephone house connections.	\$ 70.00/Ea.	14	980.00
Underground telephone cable other than house connection	\$150.00/Ea.	1	150.00
Repair storm drains damaged by Badger equipment	\$152.00/Ea.	13	1,976.00
Mobilization	\$60,000.00/Ea.	L.S.	60,000.00
Demobilization	\$ 2,000.00/Ea.	L.S.	2,000.00

Calculated Composite Sewer System Comparison

Utilizing actual contract unit costs and knowledge of construction techniques used in the field, the elements of a completed sewer section were combined in order to establish comparative costs per lineal foot of sewer placed. Certain assumptions were necessary to develop this analysis:

1. It was assumed that the hypothetical collection systems had the same number of wyes, equivalent number of manholes at similar depths, equal lateral lengths and that the repaving requirements for each system were the same.
2. The number of electric, television and telephone service disconnect and connections required for the trenchless system was the same as that encountered in the field.
3. The number of storm drains requiring restoration was the same as that encountered in the field.
4. The documented select borrow quantities for the conventional area were all attributed to the installation of gravity sewers.

The composite conventional gravity sewer system for this analysis consisted of the quantities shown in Table 9. For the complete installation of 37,367 lineal feet (11,389 m) of eight inch (20.3 cm) polyvinyl chloride gravity sewer, attendant wyes, laterals, manholes and repaving, the total project cost was \$864,891 or \$23.15/lineal foot (\$75.90/m).

Referring to Table 10, the composite trenchless gravity system consisted of 31,720 lineal feet (9,668 m) of eight inch (20.3 cm) PVC gravity sewer at a total project cost of \$615,158 or \$19.39/lineal foot (\$63.57/m).

On the basis of this last analysis, the apparent cost differential of \$6.00/lineal foot (\$19.76/m) between conventional and trenchless gravity sewer has been narrowed to \$3.76/lineal foot (\$12.33/m). However, consideration should be given to the assumptions made in using this method of analysis for a particular site. In addition, it should be noted that approximately 10% of the total construction cost for the trenchless area was for mobilization, demobilization. For a small project this significant fixed cost could entirely eliminate the differential, whereas, in a major construction project the cost for mobilization, demobilization may be insignificant. In addition, this element of contract work will be the most difficult for a designer to estimate. Therefore, in order to properly assess the potential of a trenchless program for a particular project, the designer should be aware that this lump sum cost will vary significantly depending upon the proximity of trenchless equipment to the job site at the time the contract is awarded.

TABLE 9

PAYMENT ITEMS FOR COMPOSITE CONVENTIONAL GRAVITY COLLECTION SYSTEM

<u>Description of Item</u>	<u>Quantity</u>
8" (20.3 cm) PVC Gravity Mains, complete in place, except road resurfacing.	29,691 LF (9,050 m)
8" (20.3 cm) PVC Gravity Mains complete in place, except road resurfacing, without stone bedding.	7,676 LF (2,340 m)
For furnishing and placing, complete in place, wye branch 8" x 6" (20.3 cm x 15.2 cm) PVC.	748 Each
For furnishing and placing, complete in place, except road resurfacing 6" (15.2 cm) sanitary sewer laterals to property lines.	14,940 LF (4,554 m)
For furnishing and placing standard manholes	125 Each
For furnishing grade F select borrow, complete in place, as required.	14,909 Cu.Yd. (11,405 Cu.m)
For furnishing and placing contingent stone bedding.	418 Cu.Yd. (320 Cu.m)
For furnishing and placing tar and chip bituminous surface treatment.	39,627 Sq.Yd. (33,128 Sq.m)

TABLE 10

PAYMENT ITEMS FOR COMPOSITE TRENCHLESS GRAVITY COLLECTION SYSTEM

<u>Description of Item</u>	<u>Quantity</u>
8" (20.3 cm) PVC Gravity Mains, complete in place, except road resurfacing (conventional)	2,287 LF (697 m)
8" (20.3 cm) PVC Gravity Mains, complete in place, except road resurfacing without stone bedding (conventional)	2,669.5 LF (814 m)
8" (20.3 cm) PVC Gravity Main, complete in place, except road resurfacing (trenchless)	26,764 LF (8,158 m)
For furnishing and placing complete in place wye branches 8" x 6" (20.3 cm x 15.2 cm)	634 Each
For furnishing and placing, complete in place, except for road resurfacing 6" (15.2 cm) sanitary sewer laterals to property line	12,690 LF (3,868 m)
For furnishing and placing standard manholes	106 Each
For furnishing grade F select borrow complete in place as required	7,784 Cu.Yd. (5,955 Cu.m)
For furnishing and placing contingent stone bedding	502.5 Cu.Yd. (384 Cu.m)
For furnishing and placing tar and chip bituminous surface treatment	39,627 Sq.Yd. (33,128 Sq.m)
Mobilization & Demobilization	Lump Sum
Underground cable and TV Service Repair	2 Each
Underground Electrical service repair	21 Each
Underground telephone connection repair	14 Each
Underground telephone cable other than house connection	1 Each
Storm drain repair	13 Each

It was recognized that inflation factors, labor rates and other elements which impact on construction costs would tend to limit the period during which the bid price information would be of value. In an effort to extend the useful life of the project outputs, and to afford both consultants and contractors another means of assessing the potential of the trenchless technique for a specific project, field data was assembled to develop man-day rates for both the conventional and trenchless sewer systems.

Man-Day Rate Comparison

As mentioned in Section 6, under Comparative Construction Techniques, the conventional crew was made up of a foreman, three heavy equipment operators, one pipe layer, three laborers, one engineer and one engineer's helper. The Badger crew consisted of a foreman, two equipment operators and two laborers.

Man-day rates for conventional installations were developed for the installation of gravity mains and laterals in the conventional area. The rates for main installation include excavation, placement and backfilling of 63,006 lineal feet (19,204 m) of eight, ten, twelve and fifteen inch PVC pipe (20.3, 25.4, 30.5 and 38.1 cm respectively), eight inch (20.3 cm) concrete and eight inch (20.3 cm) Asbestos Cement Pipe. Also included was the placement of 639 wyes and 191 manholes. Although the engineer and assistant have been identified as part of the conventional area construction crew, under actual field conditions they rotated between three active crews and, therefore, they were assigned, for the purpose of this analysis, one third man-day each.

The construction involved in the installation of sanitary laterals in the conventional area consisted of excavating, placing and backfilling of 11,483 lineal feet (3,500 m) of six inch (15.2 cm) PVC pipe. The lateral crew consisted of one foreman, one pipe layer, two equipment operators and two laborers.

It required 2,833 man-days to install approximately 63,000 lineal feet (19,202 m) of conventional sewer which is equivalent to 0.0450 man-days per lineal foot (0.147 man-days/m).

Because of the high water table prevalent in the area, continuous dewatering was required to install sewers in the conventional area. Two dewatering crews consisting of five persons each were active at the site for approximately three months. Discounting personnel assigned to night duty for pump observation, an additional 600 man days can be assigned to the conventional manpower tabulation or 0.010 man-days/lineal feet (0.031 man-days/m). Thus, the total labor for conventional sewer installation is 0.0550 man-days/lineal foot (0.180 man-days/m).

In the innovative area, the man-day equivalents for the gravity main consisted of the time required for set up, plowing and disconnecting during the installation of 26,764 lineal feet (8,158 m) of trenchless pipe.

One of the unique characteristics of the trenchless system is that wyes are not installed coincident with the installation of a main. The man-day requirements for lateral connections, therefore, include the excavation, placement and backfilling of 822 saddle wyes as well as 14,771 lineal feet (4,502 m) of six inch (15.2 cm) laterals.

In the Badger area, manholes were also placed after main installation. The construction of manholes included excavation, placement and backfilling of 139 manholes and includes the installation of conventional connections between the manhole and the end of trenchless pipe.

One thousand one hundred forty one man-days were required to install 26,764 lineal feet (8158 m) of trenchless sewer which is equivalent to 0.0426 man-days per lineal foot (0.140 man-days/m).

There is an obvious labor incentive in using the trenchless technique. Assuming an hourly average rate, including fringe benefits, of \$8.50/hour, the man-day analysis yields a labor savings of \$0.84/lineal foot (\$2.76/meter) compared to \$3.76/lineal foot (\$12.33/m) using the composite sewer technique and \$6.00/lineal foot (\$19.67/m) based on the bid price. Therefore, one would anticipate a cost savings by using the trenchless method regardless of the estimating technique used.

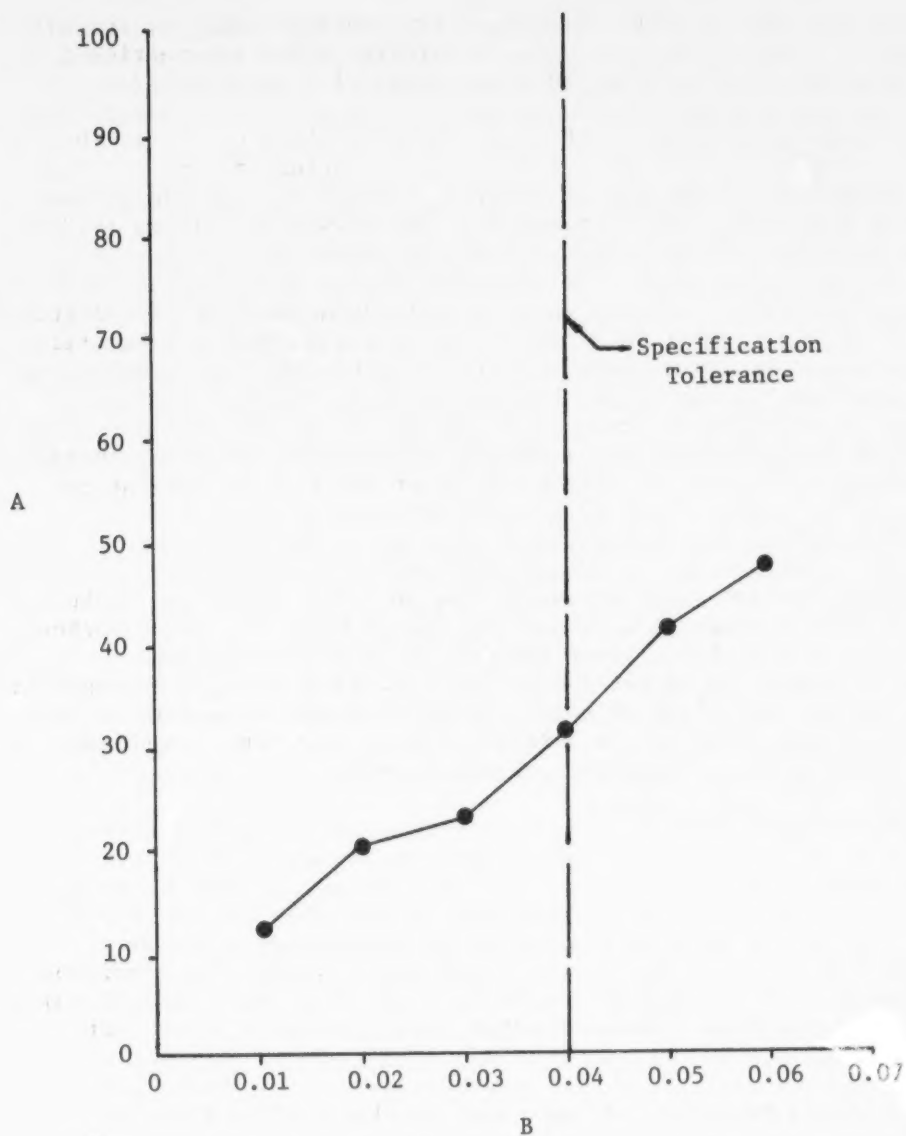
EVALUATION OF COMPLETED SYSTEM

Comparative Invert Elevations

During the project period, careful records were kept of invert elevations in both the trenchless and conventional areas. The specified vertical tolerance as measured at the manhole was $\pm 1/2$ inch (± 1.27 cm). For field control purposes, this tolerance was converted to 0.04 feet (1.22 cm).

In the conventional area, as indicated in Figure 23, 31% of the "as-built" invert elevations were within the specified tolerance whereas 47% were within .06 feet (1.83 cm). The data set for this analysis included 158 measured invert elevations. To allow for equity in comparison with the Badger system, all points in excess of 0.30 feet (9.14 cm) differential were discarded.

A number of factors contributed to this poor performance. Shipment of manholes was delayed during the early portion of conventional construction and a number of sewers were installed with gaps left between lines for subsequent manhole placement. In addition, the high water



Notes

- A. Percentage of points whose deviation from design invert elevation is less than or equal to B.
- B. Difference between "As-Built" invert elevation of conventionally installed pipe and design invert elevation.

Figure 23 Delta Invert Elevating Conventional Pipe, Project Average (As-Built).

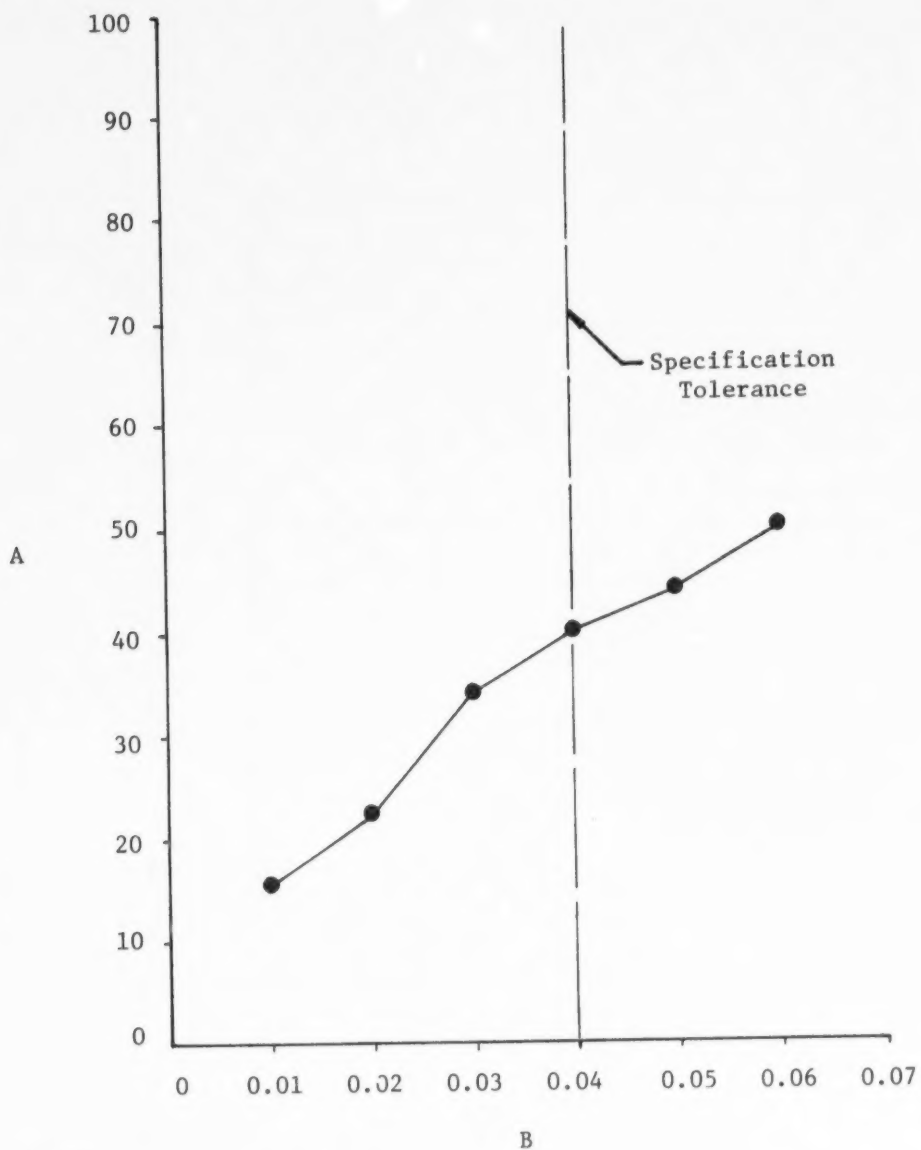
table combined with poor subsoil conditions lead to settlement of manholes in certain areas. The contractor, in an effort to offset this problem, purposely placed manholes at a higher invert elevation than specified. It was intended that natural settlement would bring the invert within the 1/2 inch (1.27 cm) tolerance.

In the Badger area, two sets of invert elevation data were obtained. In addition to normal "as-built" elevations, the invert elevations of the Badger installed pipe were measured and recorded immediately after the pull, i.e. prior to manhole placement. Referring to Figure 24, note that 40% of the trenchless area invert elevations were within the 0.04 feet (1.22 cm) tolerance and 50% fell within 0.06 feet (1.83 cm) differential based on "as-built" information. One hundred thirteen data points were used to compile this graph, but, in this case, differentials in excess of 0.30 feet (9.14 cm) were not discarded. Obviously, on the basis of "as-built" information, the Badger system was only nominally better than the conventionally installed sewers.

However, there was one factor which lead to a number of significantly high differentials in the trenchless area. Referring to Figure 25, manhole placement and conventional connection of the Badger pipe to the manhole often lead to a deviation which was far in excess of that which would have occurred had the conventionally installed pipe and manhole been installed by extending the conventional sewer on the same slope to which the Badger pipe had been laid. Therefore, the data was reassessed by computing the invert elevation in the trenchless areas by simply extending the line at installed grade to its point of intersection with the manhole.

Referring to Figure 26, the project averages on the basis of the methodology defined above show a significant improvement. Greater than 75% of the computed invert elevations were within the .04 feet (1.22 cm) tolerance. Furthermore, 88% would have been within .06 feet (1.83 cm) differential had the installations occurred in the manner prescribed. As related in Section 6, the efficiency of the Badger crew increased as the project progressed. Referring to Figure 27, a similar improvement was seen in the ability of the crew to meet the specified tolerance, once again based on a computed manhole elevation. By the end of the project, 100% of the pipe installed during the last month was within .06 feet (1.83 cm) of the design invert elevation. Eighty one percent (81%) was within the prescribed tolerance. At the beginning of the project in the month of March, only 88% of the points were within .06 feet (1.83 cm) and 73% were within the specified limits.

In summary, the care taken in the placement of connecting pipe and in setting the manhole foundation can have a major influence on the quality of the job as measured by vertical alignment. Of the 113 data points used in evaluation of the trenchless invert, 65% were felt to have been adversely affected by either manhole placement or the installation of the connecting sewer by conventional means.



Notes

- A. Percentage of points whose deviation from design invert elevation is less than or equal to B.
- B. Difference between "As-Built" invert elevation of trenchless installed pipe and design invert elevation.

Figure 24 Delta Invert Elevation, Trenchless Pipe, Project Average (As Built)

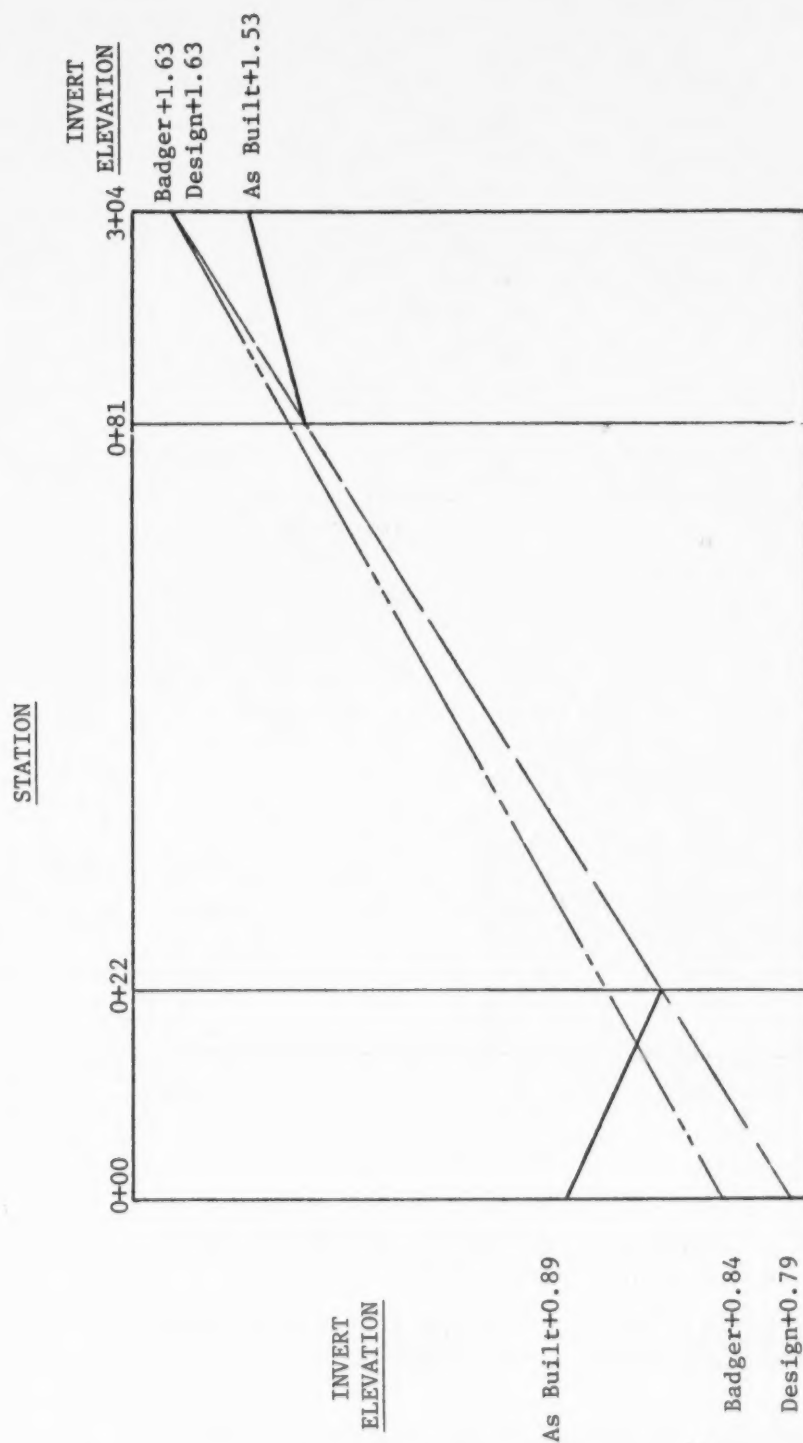
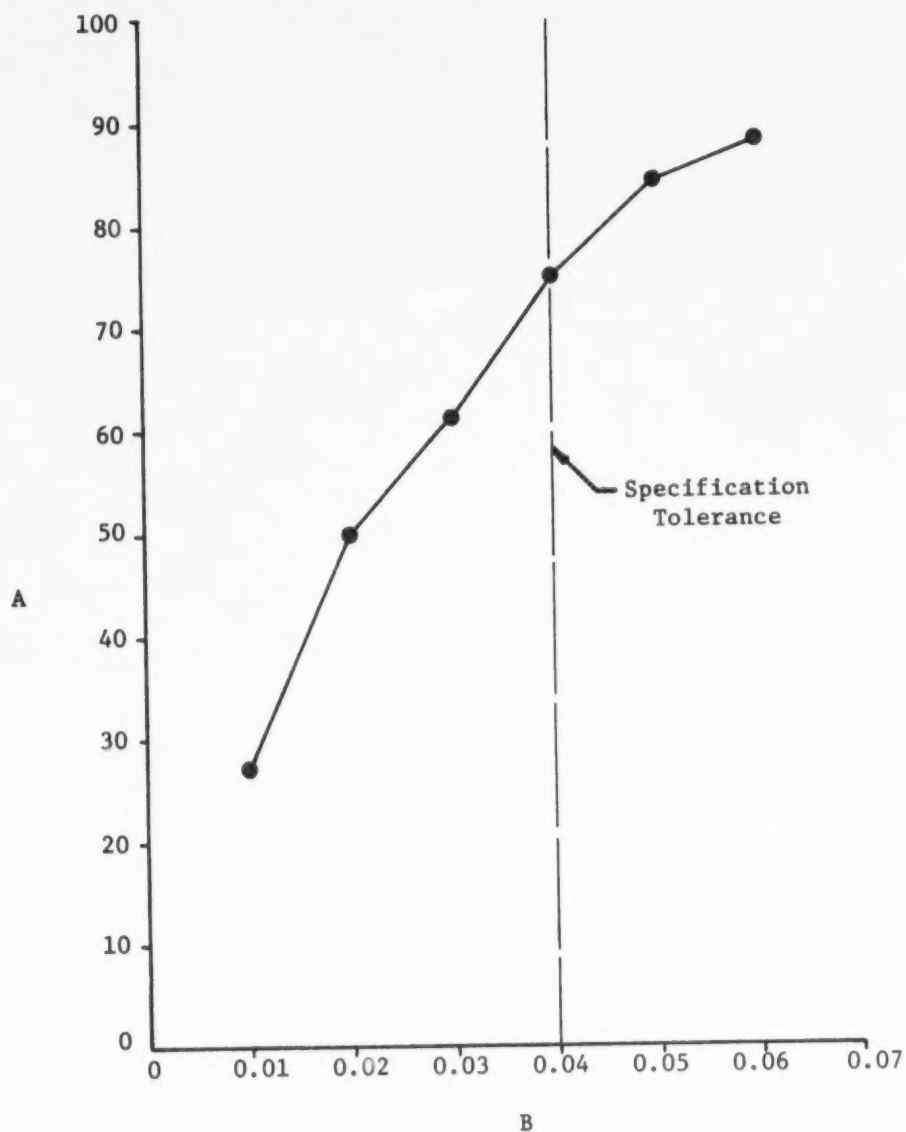


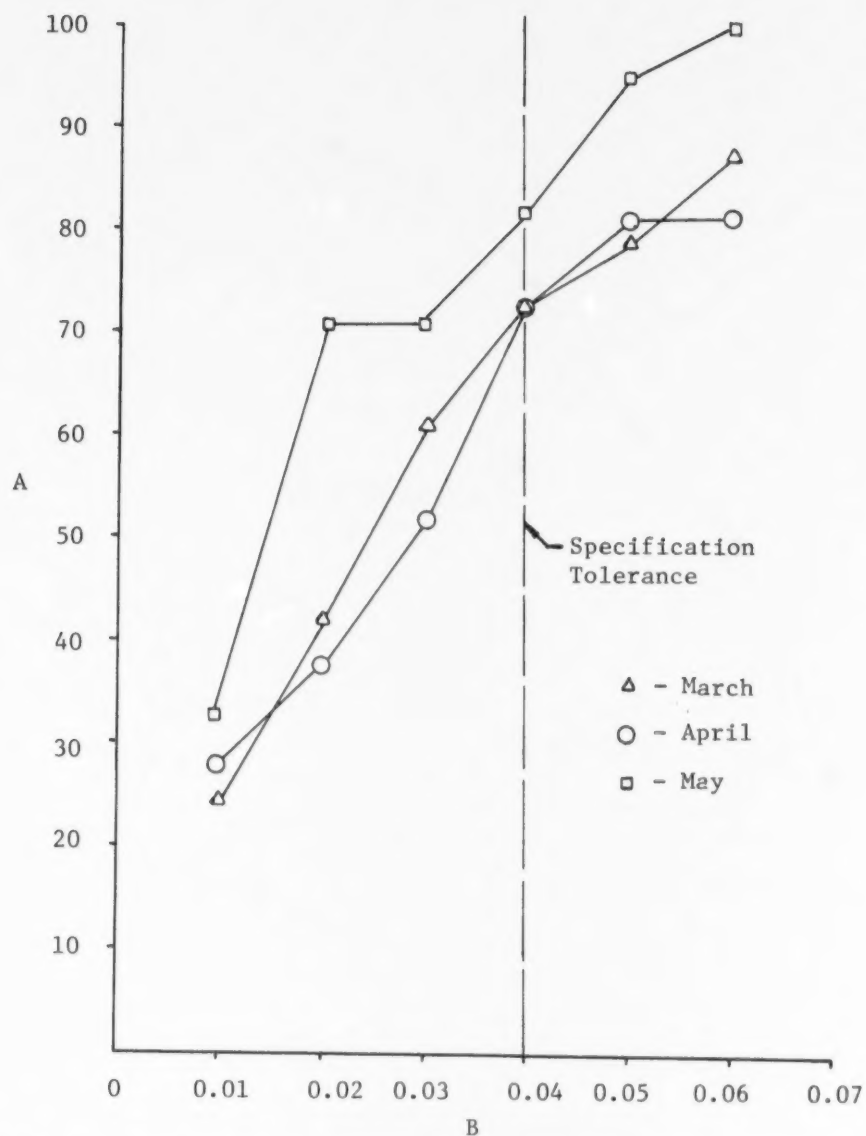
Figure 25 Effect on Final Invert Elevation of Conventional Connection of Trenchless Pipe to Manhole.



Notes

- A. Percentage of points whose deviation from design invert elevation is less than or equal to B.
- B. Difference between "Computed" invert elevation of Badger installed pipe and design invert elevation.

Figure 26 Delta Invert Elevation, Trenchless Pipe Project Average (Computed).



Note A: Percentage of points whose deviation from design invert elevation is less than or equal to B.

B: Difference between computed invert elevation of Badger installed pipe and design invert elevation.

Figure 27 Delta Invert Elevation, Trenchless Pipe, By Month (Computed)

Incremental Horizontal/Vertical Alignment

In terms of horizontal and vertical alignment requirements the basic specifications for the project required:

1. Consistently laying a sewer to grade with a vertical tolerance of $\pm .04$ feet (1.22 cm).
2. Consistently laying a sewer to line within a horizontal tolerance of ± 0.17 feet (5.2 cm).

In standard construction contracts, the resident project representative establishes compliance with vertical alignment by measuring invert elevations at the manhole and performs a mirror (lamp) test on all sewers for alignment and grade. The measured invert test is fairly sophisticated when compared with the mirror test, which requires only that the alignment be sufficiently true and straight to allow for the passage of reflected sunlight in order for the line to be accepted.

Although both of the above techniques were used to establish conformance with the design documents, a more rigorous testing procedure was developed to afford the opportunity of a more critical comparison between the trenchless and conventional techniques for these two elements of construction control.

Actual deviations in the vertical and horizontal plane were measured in fifty feet (15.24 m) increments along the sewer using a laser oriented system developed specifically for this project. A description of the methodology used is followed by an analysis of the data developed. Figures 28 through 32 are photographs taken of the technical crew during the laser alignment tests and support the following narrative. Having removed the manhole casting, the sewer is first lamped using standard techniques to determine whether or not the alignment is sufficiently true to allow passage of the laser beam. In those cases where misalignment was severe, it was so noted in a field book and the crew moved on to the next sewer length.

When an acceptable sewer is found, a nylon leadline is attached to a parachute and then the parachute is inserted into the sewer pipe, see Figure 28. The parachute serves to pull the leadline through the sewer to the upstream manhole. The leadline, of course, is used to pull the laser target through the sewer itself.

The parachute technique was found to be the optimum method after many other transport techniques were discarded either for being impractical or too time consuming. The parachute was made of tent canvas and was prevented from collapsing by the insertion of a plastic ring at the wide end. This ring had a diameter of 1/2 inch (1.22 cm) smaller than the internal diameter of the pipe. The chute itself was approximately 9 inches (22.9 cm) long.

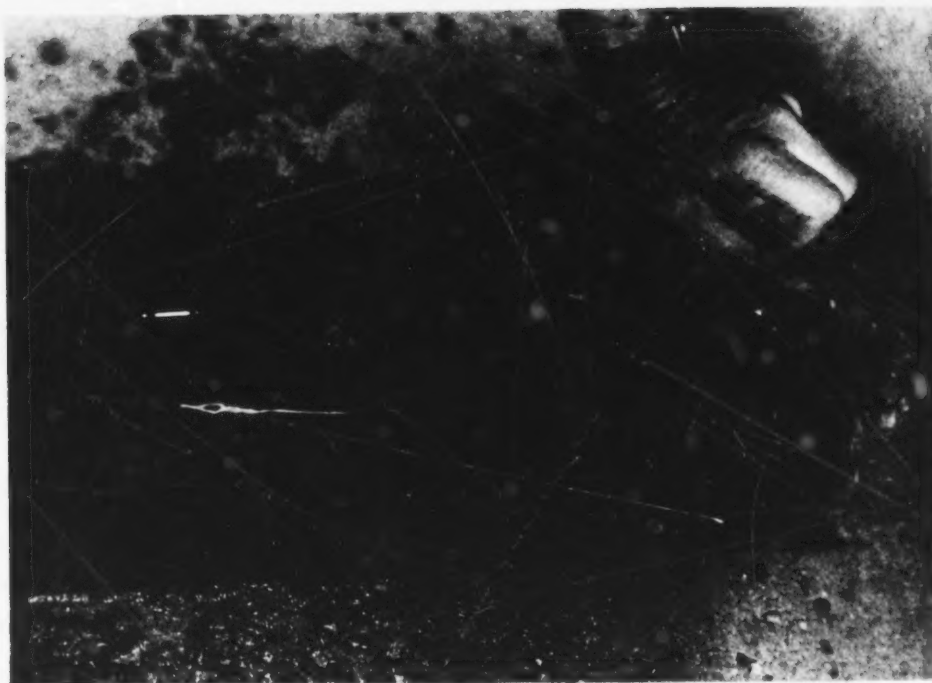


Figure 28. Parachute Insertion

Once the parachute has been inserted with the leadline attached, a 6 inch diameter flexible hose is inserted into the pipe (Figure 29). This hose is attached to a gas powered low pressured blower which provides the motive force for the parachute. With the parachute successfully retrieved at the upstream manhole, the laser target is attached to the leadline and a trailing line is also tied to the target to allow the technicians to retrieve the target in the event it becomes lodged in the pipe.

The target itself was specially designed for the project when it was discovered that commercial units had two principal deficiencies:

1. The rigid plastic material provided by most manufactureres did not have the inherent flexibility required to move the target past impediments within the pipe.
2. Most standard targets are transparent to allow the light beam to carry through the target and, as will be discussed later, this created a problem on the project.



Figure 29. Air Blower Hose Insertion

The target was mounted on two wooden skids curved on the ends similar to runners on a sled. The system was designed such that the center line of the target was always in the center line of the pipe regardless of the spatial position of the skids.

Once the target was in place, the technicians set up the laser in the manhole opposite the end at which the target was located. The laser used was a Beam Aligner as manufactured by Laser Alignment of Grand Rapids, Michigan. Referring to Figure 30, the laser output end of the beam aligner was centered in the manhole and fixed. Using a series of locks and screws, the technician at the laser end of the system maneuvered the light beam position on the target, as instructed by a technician assigned to the target station. If a misalignment prevented transmission of the light beam to the target with the laser light centered at the laser end of the system, the unit was off set and the deviation recorded so that field data collected could be modified to reflect the deviation. The centered target, prior to movement for measurement, is shown in Figure 31.

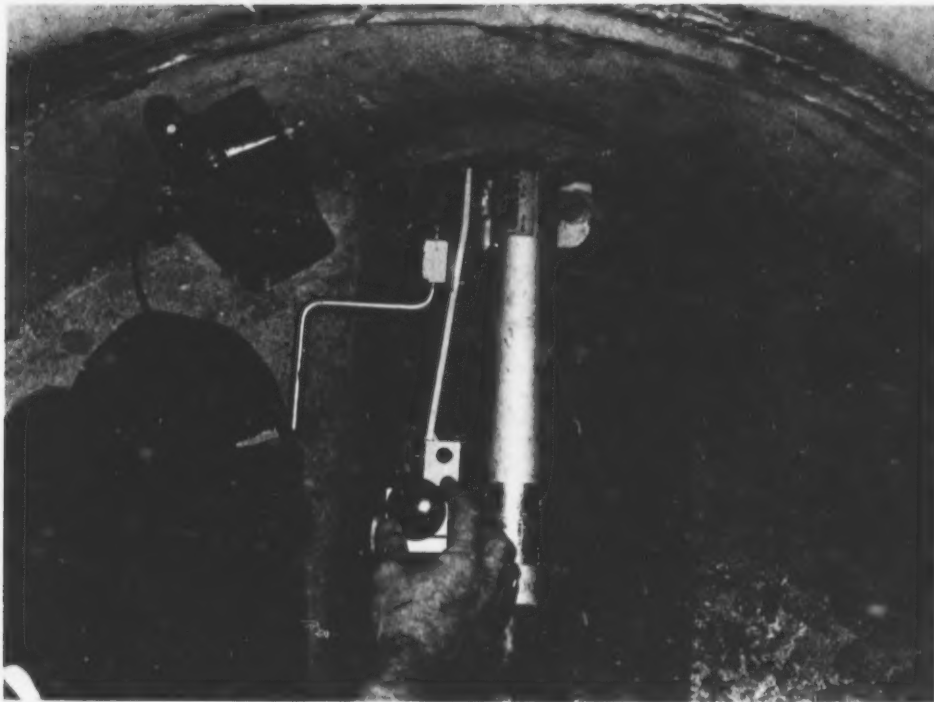


Figure 30. Placement of Laser Equipment



Figure 31. Target in Place

A chain was laid between manholes to serve as a method of recording stations as measured by the length of leadline pulled from the manhole as the target was moved forward. The technician on the target end of the sewer system used a forty-eight power monocular to determine the relative dimensions between the center of target and the location of the laser light on the target, see Figure 32. The standard target used at the outset of



Figure 32. Siting the Target

the project allowed the laser light beam to pass through the target creating a blinding red light in the monocular, thereby preventing measurement of the misalignment. The target developed for the project was translucent. The laser beam created a soft red glow at the point of contact with this translucent material and the distance between the two points was easily discerned.

Measurements were taken at 50 feet (15.24 m) increments along the sewer line and the speed with which measurements were taken was greatly facilitated when the technician developed a technique of placing the monocular on a foam rubber pad on the bench. This precluded any significant movement of the monocular which had previously made it difficult to find and then focus on the target.

Data Analysis--

As previously mentioned, the specification required compliance with a vertical tolerance of $\pm .04$ feet (1.22 cm) and, in the horizontal plane, a tolerance of ± 0.17 feet (5.2 cm). It should be noted that this specification applied only to the trenchless system, there being no tolerance requirements in the specifications for the conventional area. However, for comparative purposes, the trenchless tolerances were used to develop the figures incorporated in the text. These measurements reflect deviations at 50 feet (15.24 m) increments from manhole to manhole. For this analysis, the center line of the pipes projecting into the manholes at either end of the sighting line were considered to be at 0.00 datum both horizontally and vertically.

In the conventional area, 93% of the 42 data points conformed to the vertical tolerance whereas 60% were within the specified horizontal requirement. Of the 60,000 lineal feet (18,288 m) installed by the conventional method, only 2,000 feet (610 m) were subjected to the laser alignment test in order to provide a representative base for comparison with the trenchless sewer.

The trenchless sewer had 78% of the 155 data points within the vertical requirement. Compliance with the horizontal requirement was worse. Fifty percent of the data points were acceptable.

The resident project representative noted that there was a significant impact on sewer alignment created by the installation techniques used for installing saddle wyes and laterals. Sewer mains which had been lamped and found to be "rifle barrel" true prior to lateral installation, were subsequently lamped, and in some instances found, to allow little or no light transmission. In an effort to provide field verification for this supposition, an attempt was made to inspect virgin pipe with the laser system prior to lateral installation. Unfortunately, due to the long lead time required to develop the technique no substantive field verification was accomplished. The bases for the resident project engineer's remarks were previously discussed in Section 6 under the Technique Improvement subsection. Basically, the sewer main was found to be unstable when open cutting occurred for saddle and lateral installation. Lines not stabilized apparently had a tendency to move in both planes during backfill.

To corroborate the assumption in retrospect, the data were analyzed to determine whether there was a relationship between the number of laterals installed and the number of deviations sited. Referring to Figures 33 and 34, it is obvious that attempts to establish this correlation failed.

As in previous instances of data assessment, the data were reviewed to determine whether or not there was an improvement in technique which led to greater conformance with the specifications as the project progressed. The data points were random in nature and reflected neither an improve-

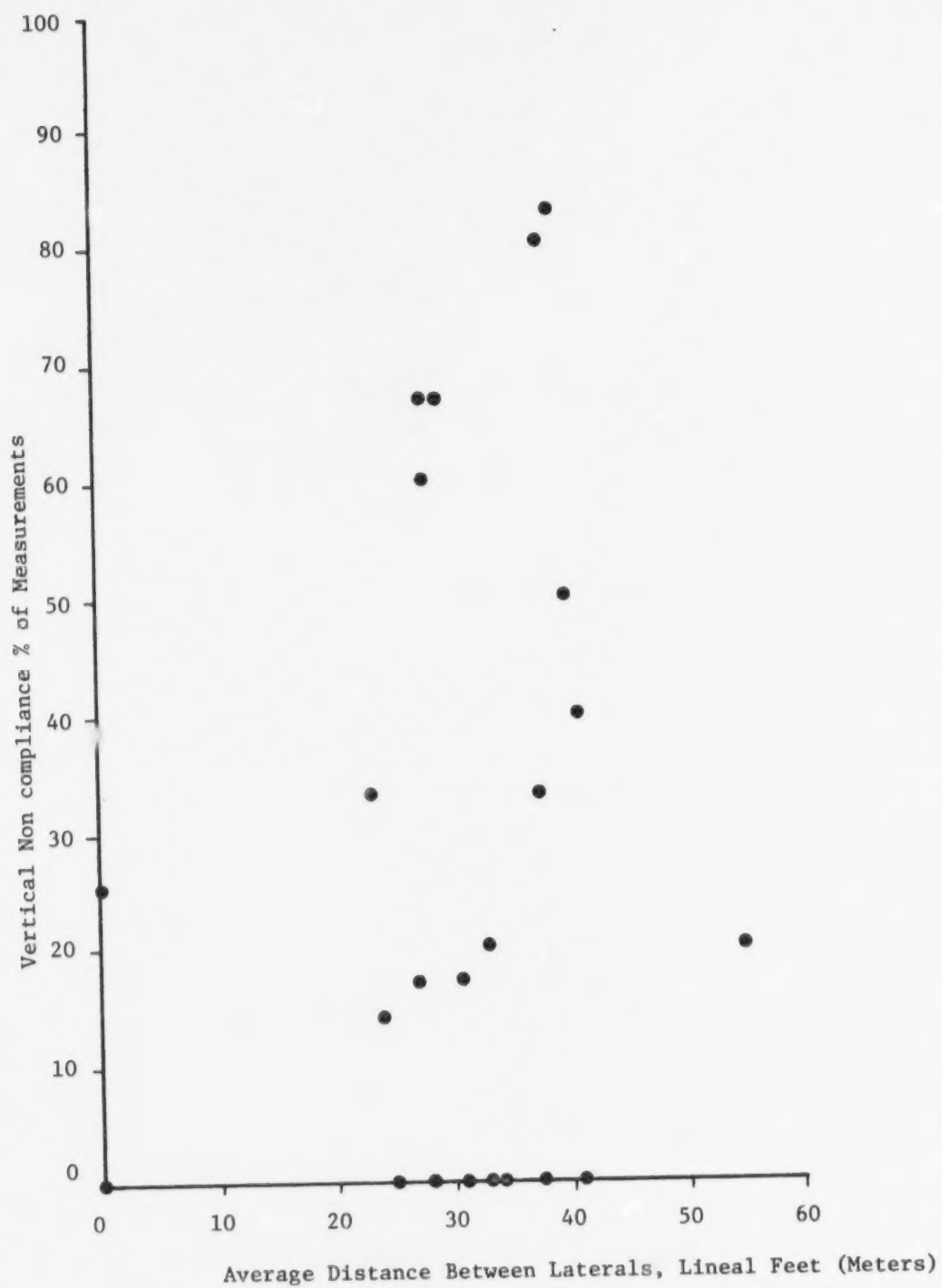


Figure 33 Relationship between vertical non-compliance and lateral density.

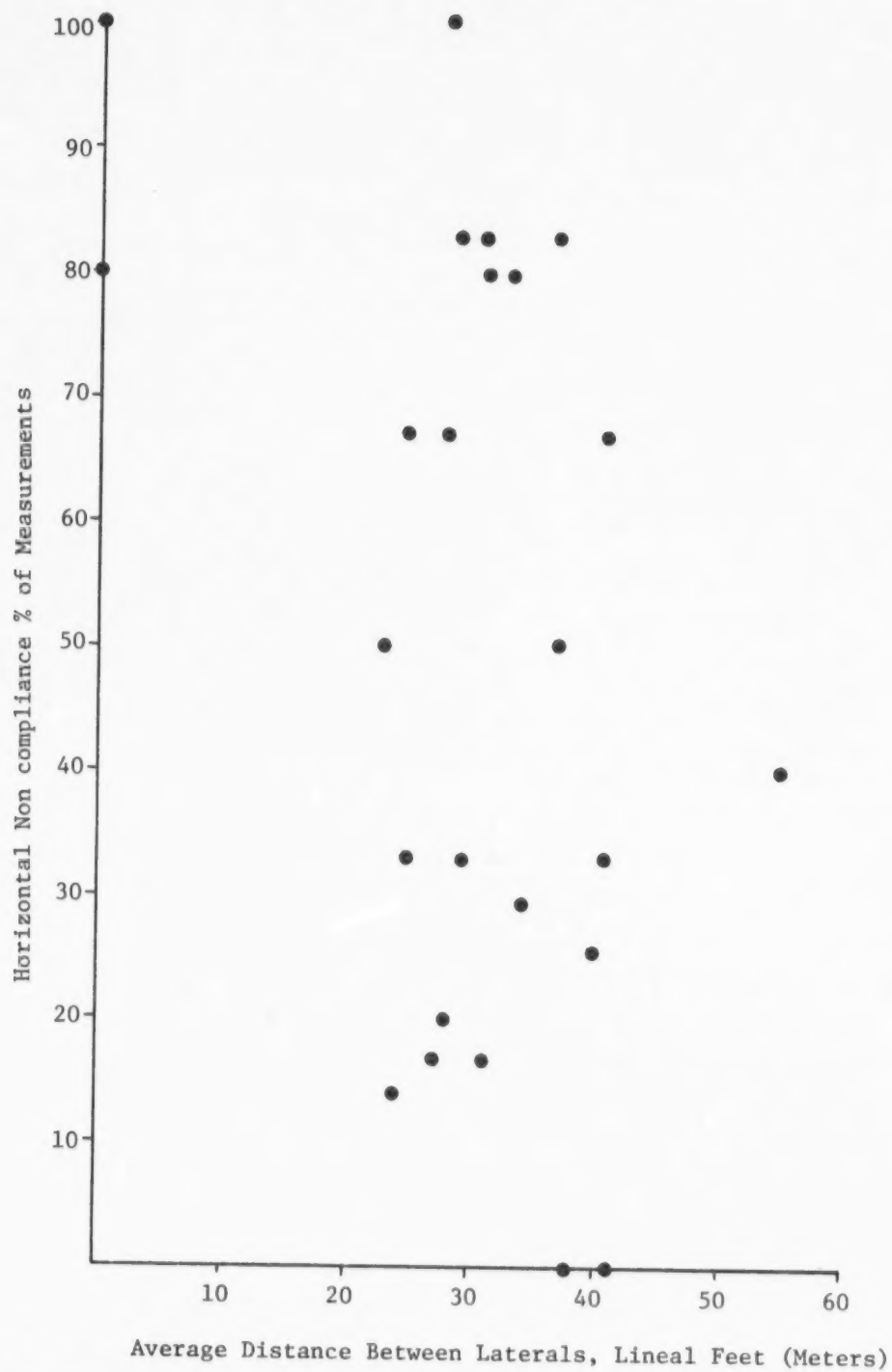


Figure 34 Relationship between horizontal non-compliance and lateral density.

ment nor degradation in construction quality with time.

Infiltration/Inflow Analysis

The Badger technique, using solvent welded pipe and rubber gaskets in precast manholes, resulted in an extremely tight sewer. The Sussex County Engineer's office will not allow an infiltration rate in excess of 50 gallons per inch of pipe diameter per mile of pipe for twenty four hours. In the trenchless area, the sewers were found to be water tight as measured by the standard infiltration test. No water was observed. In the conventional area, the measured flowmeter for two sub-drainage areas ranged between 16 and 44 gallons per inch of pipe diameter per mile of pipe for twenty four hours. In all cases this rigid infiltration requirement was met. Water tight manhole inserts, as manufactured by Methods Engineering Corporation, contributed significantly to the overall dryness of each of the systems.

Closed Circuit Internal Television Inspection

Twenty thousand lineal feet (6096 m) of trenchless sewer was inspected using internal television inspection techniques to support the infiltration analysis findings and to provide an historical record of the internal condition of the system prior to placing it into operation. With the exception of dips in the line which were also found during the laser alignment phase, only one problem was identified. An offset joint was observed midway between two manholes in the Bayview Park area but was not observed to be leaking at the time the camera passed.

ENVIRONMENTAL ASPECTS

Groundwater Quality

The only factor of environmental concern for which the project specifically required the development of quantitative data was the potential for the trenchless technique to limit degradation of groundwater quality. Background information was obtained at ten sampling points located throughout the trenchless area, see Figure 35, for thirty three (33) parameters including heavy metals. In some instances, wells were not installed in time to obtain more than one background sample. However, background data are available for all sampling points.

After construction was initiated, four additional samples were taken before it became obvious that no particular pattern was developing and the program was concluded. The analyses are presented here in Tables 11 through 20.

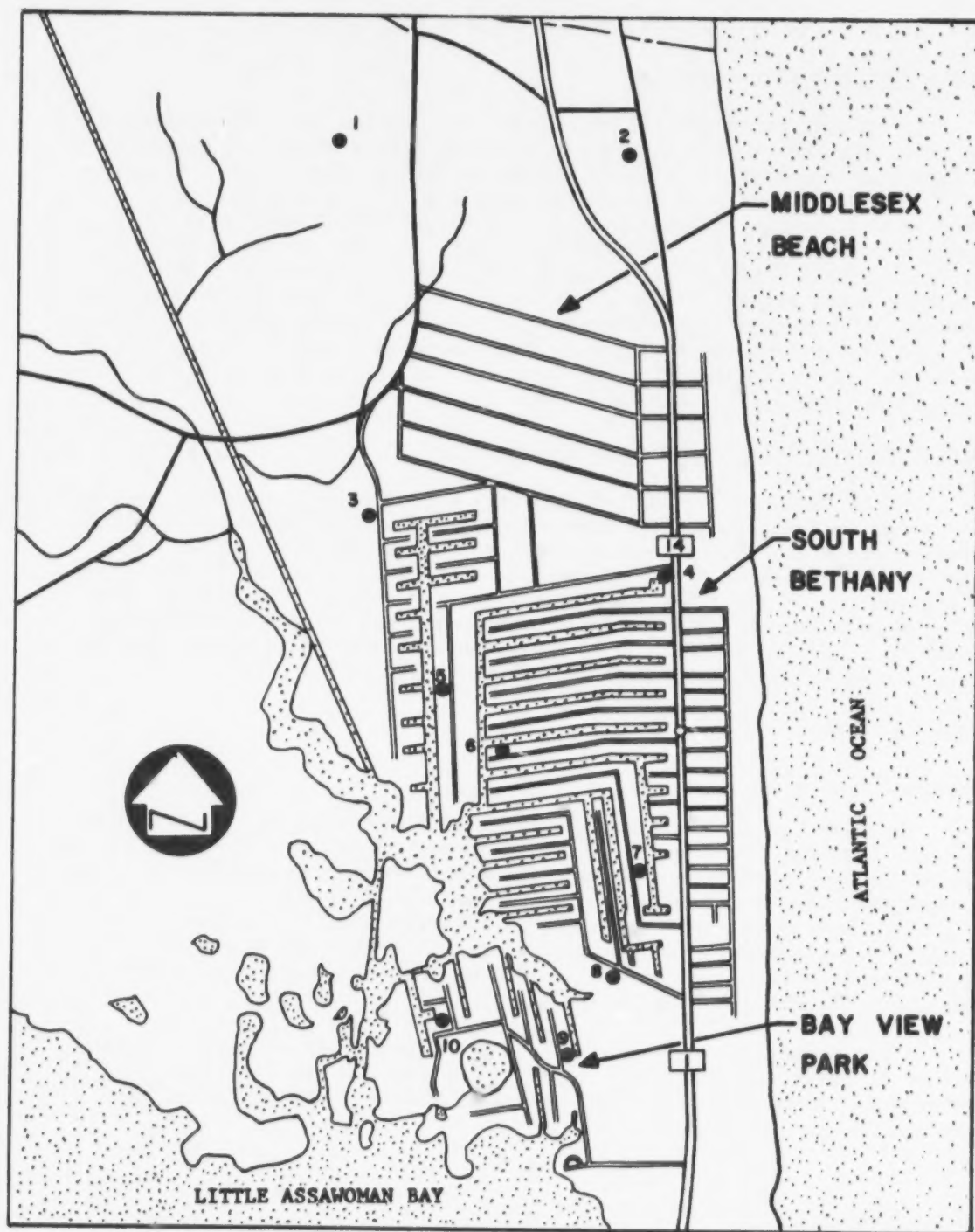


Figure 35 Groundwater Quality Monitoring Well Locations

TABLE 11

Groundwater Quality Data*

Well No. 1

Parameters	Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6
BOD ₅	5.0		5.7	<2.4	<2.4	14
COD	32		20			
Alkalinity as CaCO ₃	3					
Acidity as CaCO ₃	13		48			
Specific Conductance, μ mhos/l	280		1020			
Temperature °C	9.0		18			
Detergent, MBAS	<0.1		0.1			
Oil & Grease	1		<1			
Total Coliform, #/100 ml	<10		<10	>800	<10	300
Fecal Coliform, #/100 ml	<10		<10	>800	<10	<10
Total Kjeldahl Nitrogen as N	0.11		0.19			
Organic Nitrogen as N	<0.10		0.19			
Ammonia Nitrogen as N	0.11		<0.10			
Nitrite Nitrogen as N	<0.04		<0.04	0.11	0.21	0.10
Nitrate + Nitrite as N	0.14		0.15			
Total Phosphate as P	<0.17		<0.2			
Chloride	520		260	120	80	19
Hardness, as CaCO ₃	46		131			
Manganese	0.13		0.28			
Iron	1.1		0.88			
Lead	<0.05		<0.05			
Copper	<0.05		0.12			
Chromium	<0.05		<0.05			
Zinc	0.26		1.1			
Mercury, μ g/l	<0.5		<0.5			
Cadmium	<0.01		0.05			
Settleable Solids, ml/l	10		19			
Total Suspended Solids	1010		3100	1290	1670	12
Non-Volatile Solids	950		2850			
Volatiles Suspended Solids	60		250			
Total Solids	1210		3600			
Non-Volatile Total Solids	1100		3250			
Volatiles Total Solids	110		350			

TABLE 12

Groundwater Quality Data

Well No. 2

Parameters	Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6
BOD ₅	<2.4	<2.4	<2.4	3.8	<2.4	
COD	<5	12	12			
Alkalinity as CaCO ₃	7	5	69			
Acidity as CaCO ₃	16	49	27			
Specific Conductance, μ mhos/l	250	300	280			
Temperature °C	7.0	8.0	18			
Detergent, MBAS	<0.10	<0.1	0.12			
Oil & Grease	3	<1	<1			
Total Coliform, #/100ml		10	<10	10	<10	
Fecal Coliform, #/100ml		<10	<10	<10	<10	
Total Kjeldahl N, as N	<0.10	<0.10	<0.1			
Organic Nitrogen as N	<0.10	<0.10	<0.1			
Ammonia Nitrogen as N	<0.10	<0.10	0.10			
Nitrite Nitrogen as N	<0.04	<0.04	<0.04	<0.04	<0.04	
Nitrate + Nitrite as N	<0.04	0.20	<0.04			
Total Phosphate as P	<0.17	<0.17	<0.2			
Chloride	62	500	40	76	80	
Hardness, as CaCO ₃	20	30	110			
Manganese	<0.05	<0.05	0.36			
Iron	0.24	0.3	2.0			
Lead	<0.05	<0.05	<0.05			
Copper	<0.05	<0.05	<0.05			
Chromium	<0.05	<0.05	<0.05			
Zinc	0.08	<0.10	<0.10			
Mercury, μ g/l	0.8	<0.5	<0.5			
Cadmium	<0.01	<0.01	<0.01			
Settleable Solids, ml/l	<0.2	0.5	<0.1	460	1	
Total Suspended Solids	19	40	9			
Non-Volatile SS	15	20	7			
Volatiles SS	4	20	2			
Total Solids	140	160	190			
Non-Volatile T. Solids	130	140	130			
Volatiles Total Solids	10	20	60			

*Units are mg/l except as noted

TABLE 13

Groundwater Quality Data

Well No. 3

Parameters	Pre Construction		During Construction	
	#1	#2	#3	#6
BOD ₅	2.7	2.7	<2.4	2.4
COD	24	32	24	2.4
Alkalinity as CaCO ₃	33	27	18	
Acidity as CaCO ₃	26	34	61	
Specific Cond., μ mhos/l	590	500	2200	
Temperature, °C	6.5	9.0	17	
Detergent, MBAS	<0.10	<0.1	0.3	
Oil & Grease	<1	<1	<1	
Total Coliform, #/100ml	10	10	<10	<1
Fecal Coliform, #/100ml	<10	<10	<10	<10
Total Kjeldahl N, as N	<0.10	<0.10	0.37	
Organic Nitrogen as N	0.27	0.20	<0.1	
Ammonia Nitrogen as N	0.27	0.20	0.38	
Nitrite Nitrogen as N	<0.04	<0.04	<0.04	<0.05
Nitrate +Nitrate as N	<0.04	<0.04	<0.04	
Total Phosphate as P	<0.17	<0.17	<0.2	
Chloride	140	620	710	320
Hardness, as CaCO ₃	66	40	260	520
Manganese	0.1	<0.05	0.08	
Iron	5.4	4.5	18	
Lead	<0.05	<0.05	<0.05	
Copper	<0.05	<0.05	<0.05	
Chromium	<0.05	<0.05	<0.05	
Zinc	<0.10	<0.10	0.19	
Mercury, μ g/l	1.3	1.9	<0.5	
Cadmium	<0.01	<0.01	<0.01	
Settleable Solids, ml/l	0.5	0.3	3.5	
Total Suspended Solids	190	100	30	30
Non-Volatile SS	180	90	20	
Volatile SS	10	10	10	
Total Solids	640	610	1270	
Non-Volatile T. Solids	570	580	1060	
Volatile Total Solids	70	30	210	

TABLE 14

Groundwater Quality Data

Well No. 4

Parameters	Pre Construction		During Construction	
	#1	#2	#3	#6
BOD ₅	<2.4		<2.4	9.6
COD	64		43	
Alkalinity as CaCO ₃	90		51	
Acidity as CaCO ₃	28		35	
Specific Cond., μ mhos/l	9400		1100	
Temperature, °C	8.0		18	
Detergent, MBAS	0.14		0.12	
Oil & Grease	<1		<1	
Total Coliform, #/100ml			<10	<10
Fecal Coliform, #/100ml			<10	<10
Total Kjeldahl N, as N	1.11		1.25	
Organic Nitrogen as N	<0.10		<0.1	
Ammonia Nitrogen as N	1.11		1.3	
Nitrite Nitrogen as N	<0.06		<0.04	<0.04
Nitrate +Nitrate as N	<0.04		<0.04	<0.05
Total Phosphate as P	<0.17		<0.2	
Chloride	4000		4300	2700
Hardness, as CaCO ₃	1100		1220	4500
Manganese	0.26		0.19	2020
Iron	2.2		2.6	
Lead	<0.05		0.10	
Copper	<0.05		<0.05	
Chromium	<0.05		<0.05	
Zinc	0.14		<0.10	
Mercury, μ g/l	<0.5		<0.5	
Cadmium	<0.01		<0.01	
Settleable Solids, ml/l	0.3		0.2	
Total Suspended Solids	60		100	60
Non-Volatile SS	50		100	40
Volatile SS	10		0	30
Total Solids	5540		6800	
Non-Volatile T. Solids	4960		5800	
Volatile Total Solids	580		1000	

TABLE 15

Groundwater Quality Data

Well No. 5

Parameters	Pre Construction			During Construction			Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6	#1	#2	#3	#4	#5	#6
BOD ₅	9.6	3.6	3.6	3.6	3.5*	2.4	62					
COD	92	92	78									
Alkalinity as CaCO ₃	350	290	710									
Acidity as CaCO ₃	19	37	69									
Specific Cond., μ mhos/l	3500	5300	9000									
Temperature, °C	8.0	2.0	17									
Detergent, MBAS	0.17	0.1	0.16									
Oil & Grease	<1	<1	10									
Total Coliform, #/100ml	190	<10	<10	<10	<10	200						
Fecal Coliform, #/100ml	<10	<10	<10	<10	<10	<10						
Total Kjeldahl N, as N	4.1	4.3	6.25									
Organic Nitrogen as N	0.3	<0.10	0.25									
Ammonia Nitrogen as N	3.8	4.3	6.0									
Nitrite Nitrogen as N	<0.04	<0.04	<0.04	<0.04	<0.04	0.16						
Nitrate Nitrogen as N	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04						
Total Phosphate as P	<0.17	<0.17	0.3									
Chloride	1150	900	3200	2700	2800	310						
Hardness, as CaCO ₃	380	550	1010									
Manganese	0.18	0.14	0.26									
Iron	0.28	3.2	4.8									
Lead	<0.05	<0.05	0.08									
Copper	<0.05	<0.05	<0.05									
Chromium	<0.05	<0.05	<0.05									
Zinc	<0.05	<0.10	<0.10									
Mercury, μ g/l	4.3	3.4	3.6									
Cadmium	<0.01	<0.01	<0.01									
Settleable Solids, ml/l	<0.1	<0.1	<0.1	80	30	312						
Total Suspended Solids	80	30	50									
Non-Volatile SS	80	30	40									
Volatile SS	0	0	10									
Total Solids	1950	3050	5360									
Non-Volatile T. Solids	1760	3900	4730									
Volatile Total Solids	190	250	630									

TABLE 16

Groundwater Quality Data

Well No. 6

Parameters	Pre Construction			During Construction			Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6	#1	#2	#3	#4	#5	#6
BOD ₅	<2.4*	4.5										
COD	110	120										
Alkalinity as CaCO ₃	200	530										
Acidity as CaCO ₃	38	35										
Specific Cond., μ mhos/l	5400	4000										
Temperature, °C	6.0	9.0										
Detergent, MBAS	<0.10	0.66										
Oil & Grease	<1	<1										
Total Coliform, #/100ml	200	200										
Fecal Coliform, #/100ml	<10	<10										
Total Kjeldahl N, as N	3.50	12.5										
Organic Nitrogen as N	0.75	0.10										
Ammonia Nitrogen as N	2.75	12.5										
Nitrite Nitrogen as N	<0.04	<0.04										
Nitrate Nitrogen as N	<0.04	<0.04										
Total Phosphate as P	<0.17	<0.17										
Chloride	1750	860										
Hardness, as CaCO ₃	720	470										
Manganese	1.5	0.45										
Iron	2.6	7.5										
Lead	<0.05	<0.05										
Copper	<0.05	<0.05										
Chromium	<0.05	<0.05										
Zinc	0.20	<0.10										
Mercury, μ g/l	<0.5	0.8										
Cadmium	<0.01	<0.01										
Settleable Solids, ml/l	<0.1	<0.1										
Total Suspended Solids	20	40										
Non-Volatile SS	18	40										
Volatile SS	2	0										
Total Solids	3070	2240										
Non-Volatile T. Solids	2780	2040										
Volatile Total Solids	290	200										

TABLE 17

Groundwater Quality Data

Well No. 7

Parameters	Pre Construction		During Construction	
	#1	#2	#3	#4 #5 #6
BOD ₅	<2.4*		<2.4	<2.4 2.6* 8.4
COD	16		170	
Alkalinity as CaCO ₃	21		66	
Acidity as CaCO ₃	19		26	
Specific Cond., μ mhos/l	150		625	
Temperature, °C	4.0		17	
Detergent, MBAS	0.10		0.26	
Oil & Grease	<1		<1	
Total Coliform, #/100ml			<10	<10 <10 <1
Fecal Coliform, #/100ml			<10	<10 <10 <10
Total Kjeldahl N, as N	0.40		3.16	
Organic Nitrogen as N	<0.10		1.56	
Ammonia Nitrogen as N	0.40		1.6	
Nitrite Nitrogen as N	<0.04		<0.04	0.15 0.31 0.08
Nitrate +Nitrate as N	0.24		<0.04	
Total Phosphate as P	<0.17		<0.2	
Chloride	27		200	850 400 210
Hardness, as CaCO ₃	38		99	
Manganese	<0.05		0.12	
Iron	0.86		3.5	
Lead	<0.05		<0.05	
Copper	<0.05		<0.05	
Chromium	<0.05		<0.05	
Zinc	0.08		<2.4	
Mercury, μ g/l	1.6		<2.4	
Cadmium	<0.01		0.01	
Settleable Solids, ml/l	<0.1		<0.1	
Total Suspended Solids	18		30	16 4 20
Non-Volatile SS	12		20	
Volatile SS	6		10	
Total Solids	110		580	
Non-Volatile T. Solids	60		380	
Volatile Total Solids	50		200	

TABLE 18

Groundwater Quality Data

Well No. 8

Parameters	Pre Construction		During Construction	
	#1	#2	#3	#4 #5 #6
BOD ₅	3.1*	9.6	2.7	30* <2.4 7.4
COD	84	160	71	
Alkalinity as CaCO ₃	310	330	255	
Acidity as CaCO ₃	50	42	33	
Spec. Cond., μ mhos/l	10,400	11,400	12,800	
Temperature, °C	9.0	9.0	16	
Detergent, MBAS	0.10	0.1	0.21	
Oil & Grease	<1	1	<1	<10 <10 <1
Total Coliform, #/100ml		<10	<10	<10 <10 <10
Fecal Coliform, #/100ml		<10	<10	
Total Kjeldahl N, as N	3.10	3.5	2.1	
Organic Nitrogen as N	0.16	<0.10	<0.1	
Ammonia Nitrogen as N	2.94	3.5	2.3	
Nitrite Nitrogen as N	<0.04	<0.04	<0.04	<0.04 <0.04 <0.05
Nitrate +Nitrate as N	<0.04	<0.04	<0.04	
Total Phosphate as P	0.27	0.31	0.2	
Chloride	6500	1000	5100	
Hardness, as CaCO ₃	1000	1300	1260	
Manganese	6.36	0.14	0.62	
Iron	1.1	1.2	4.3	
Lead	<0.05	<0.05	0.11	
Copper	<0.05	<0.05	<0.05	
Chromium	<0.05	<0.05	<0.05	
Zinc	0.54	<0.10	<0.10	
Mercury, μ g/l	0.5	1.7	<0.5	
Cadmium	<0.01	<0.01	<0.01	
Settleable Solids, ml/l	<0.1	<0.1	0.1	
Total Suspended Solids	17	90	30	50 3 4
Non-Volatile SS	11	80	20	
Volatile SS	6	10	10	
Total Solids	6110	6720	7960	
Non-Volatile T. Solids	5610	6130	7070	
Volatile Total Solids	500	590	890	

TABLE 19

Groundwater Quality Data

Well No. 9

Parameters	Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6
BOD ₅		3.5		28	<2.4	2.9
COD		32				
Alkalinity as CaCO ₃		64				
Acidity as CaCO ₃		57				
Specific Cond. μ hos/l		520				
Temperature, °C		11.0				
Detergent, MBAS		<0.1				
Oil & Grease		1				
Total Coliform, #/100ml		10		<10	<10	70
Total Kjeldahl N, as N		<10		<10	<10	<10
Organic Nitrogen as N		0.16				
Ammonia Nitrogen as N		<0.10				
Nitrite Nitrogen as N		0.16				
Nitrate + Nitrite as N		<0.04		<0.04	<0.04	<0.05
Total Phosphate as P		<0.04				
Chloride		<0.17				
Hardness, as CaCO ₃		440		740	1900	45
Manganese		150				
Iron		0.9				
Lead		12.5				
Copper		<0.05				
Chromium		<0.05				
Zinc		0.18				
Mercury, μ g/l		3.9				
Cadmium		<0.01				
Settleable Solids, ml/l		0.7				
Total Suspended Solids		160		90	80	220
Non-Volatile SS		130				
Volatile SS		30				
Total Solids		470				
Volatile Total Solids		60				

TABLE 20

Groundwater Quality Data

Well No. 10

Parameters	Pre Construction			During Construction		
	#1	#2	#3	#4	#5	#6
BOD ₅		7.6	2.9	24	3.1	20
COD		84	55			
Alkalinity as CaCO ₃		58	57			
Acidity as CaCO ₃		28	36			
Specific Cond. μ hos/l		640	1900			
Temperature, °C		11.0	17			
Detergent, MBAS		<0.1	0.18			
Oil & Grease		<1	<1			
Total Coliform, #/100ml		<10	10	<10	*	<1
Fecal Coliform, #/100ml		<10	<10	<10	150	<10
Total Kjeldahl N, as N		2.20	2.0			
Organic Nitrogen as N		<0.1	<0.1			
Ammonia Nitrogen as N		2.20	2.44			
Nitrite Nitrogen as N		<0.04	<0.04	<0.04	<0.04	<0.05
Nitrate + Nitrite as N		<0.04	<0.04			
Total Phosphate as P		<0.17	<0.2			
Chloride		1000	560	2300	580	190
Hardness, as CaCO ₃		170	336			
Manganese		0.2	6.31			
Iron		4.0	2.7			
Lead		<0.05	0.06			
Copper		<0.05	<0.05			
Chromium		<0.05	<0.05			
Zinc		<0.10	<0.10			
Mercury, μ g/l		1.1	0.7			
Cadmium		<0.01	<0.01			
Settleable Solids, ml/l		13.0	<0.1			
Total Suspended Solids		1350	30	900	880	2110
Non-Volatile SS		1250	30			
Volatile SS		100	0			
Total Solids		1900	1230			
Volatile Total Solids		1720	990			
Volatile TS		180	240			

Other Environmental Aspects

The trenchless technique appears to have certain qualitative benefits in the areas of noise, sediment runoff, energy consumption and safety.

The conventional method requires the use of heavy equipment to open trench and the noise from this equipment is constant, almost from the time trenching begins until backfill is completed. With the Badger method, however, motor noise is limited to those limited periods when open trenching occurs for lead trench cutting, a brief pull period by the Badger, and open trenching for pipe connection and lateral installation.

With regard to sediment runoff, the only period during which there is significant exposed raw earth is during lateral installation. This, of course, was not a factor on this particular project due to the flat terrain and the prevailing dry weather which occurred during construction.

It is unfortunate that no quantitative information was developed on the fuel consumption associated with both conventional and Badger techniques. Energy was not a prime concern at the time when the demonstration application was filed. However, the run time of heavy equipment is obviously less using the trenchless technique for substantially the same reasons prescribed to the noise level associated with each system.

No significant accidents occurred in either the conventional or innovative areas during the construction period.